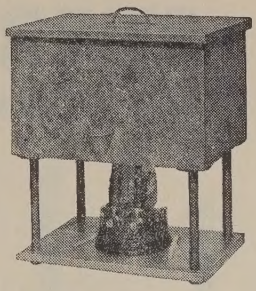
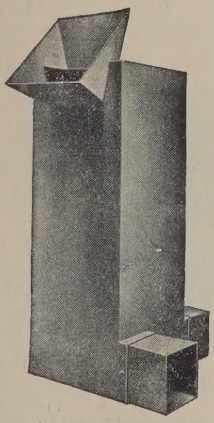
THE NELLIK SOIL STERILIZER

A HANDY SMALL STERILIZER AND A SIMPLE STEAM METHOD OF MAKING THE SOIL CLEAN AND FREE FROM PESTS, WEED SEEDS, ETC.

● Approx. capacity 3 cwt.

OIL OR ELECTRIC

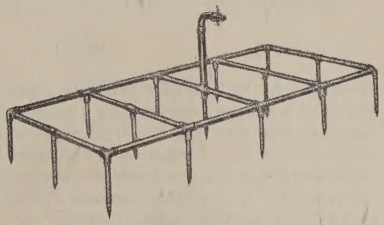




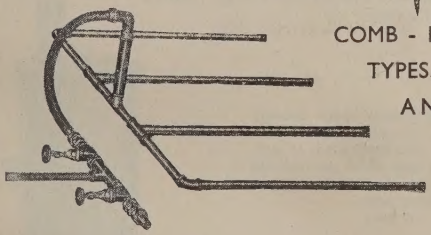
VULCAN SOIL STERILIZER

HOLMES ORIGINAL PATENT No. 9057, AS USED ON LARGE NURSERY GARDENS, ENSURING CLEAN, WHOLESOME AND FERTILE SOIL.

● Approx. capacity 1 yard.



STEAM GRIDS



COMB - HARROW - HODDESDON TYPES, DISTRIBUTORS, BOILERS, AND ALL ANCILLARY EQUIPMENT SUPPLIED.

● SEND YOUR ENQUIRIES AND PROBLEMS TO:—

CHAS. P. KINNELL & Co. Ltd.

65, 65A SOUTHWARK ST., LONDON, S.E.1. 'Phone WATERLOO 4144

First published January, 1931
Fifth edition, October, 1959

The Ministry does not accept responsibility for any of the private or trade advertisements included in this publication

Foreword

THE previous edition of this bulletin was published over eleven years ago. In the meantime steam sterilization has been the subject of further research, particularly at the National Institute of Agricultural Engineering and the John Innes Horticultural Institution, and more precise information on the heating process in the soil and the practical procedures of soil treatment has been obtained. Complementary developments in glasshouse and boiler design, and improvements in steam main and distributor equipment have also played a part in easing the practice and improving its economics. While the Hoddesdon pipe and its modifications are still the mainstay of steaming equipment, most other methods previously described have become obsolete. On the other hand, the possibility of mechanizing the process with a saving in labour effort and cost has recently become practicable. In chemical treatment of the soil, the main feature has been the appearance of new materials for specific use against soil-borne troubles, and the hope for better control of soil infection in glasshouses is thus renewed.

In this fifth edition, the text has been entirely rewritten in the light of these and other developments. This work has been the general responsibility of the Glasshouse Group of the National Agricultural Advisory Service, now under the chairmanship of Mr. F. W. Toovey, B.Sc., A.R.C.S., A.I.C.T.A., Director of the Glasshouse Crops Research Institute. The Group is particularly indebted to Mr. L. G. Morris (National Institute of Agricultural Engineering) and Mr. W. J. C. Lawrence (John Innes Horticultural Institution) for advice and help, and to the members of the Working Party, Messrs. J. Rhodes, G. F. Sheard, G. P. Shipway, E. E. Skillman and R. T. Pearl, who undertook the task of preparing the text for publication.

September, 1959 *Ministry of Agriculture, Fisheries and Food*

Contents

	Page
Introduction	1
Effects of Soil Sterilization	2
Sterilization by Steam	
Properties of Steam	4
Heating of Soil by Steam	5
Boilers and Steam Production	11
Methods of Soil Steaming	15
Sterilizing Small Quantities of Soil	27
Sterilization by Chemicals	31
Soil Treatment after Sterilization	37
Layout of Soil Sheds	39
Appendices	
I. *Summary of Points in Steam Sterilization*	42
II. *Guide to Costs of Soil Sterilization*	46
III. *Properties of Steam*	47
IV. *Flow of Steam through Mains and Perforated Pipes*	49

Introduction

THE practice of partial sterilization of the soil in glasshouses has been established for many years. It is well known that plants cannot make normal growth if their roots are unhealthy, and although in fresh or virgin soil healthy roots are taken for granted, in glasshouses the same crop may be grown year after year, with the result that sooner or later the soil becomes "sick", and healthy root growth is then the exception rather than the rule.

The soil is teeming with life, which ranges from the largest forms visible to the eye, such as insects and earthworms, to the microscopic fungi, bacteria, protozoa, and even a few of the viruses. The micro-organisms, especially the bacteria, play a most important part in the transformations which go on in the soil, particularly in the decomposition of plant and animal remains and added manure. Many soil organisms are beneficial and their activities result in changes which set free plant nutrients, but some organisms may bring about the loss of valuable constituents. Furthermore, competition between different organisms for the same material may upset the balance in the soil and deny essential supplies to the crops being grown. Unfavourable conditions of aeration, supply of water, organic matter or mineral nutrients also affect relationships; they may tip the balance against the crops or alter the soil population or result in harmful activities by soil micro-organisms.

Pest and disease-producing organisms include some that live naturally in the soil and usually obtain all their needs from it, but when a crop is weakened by adverse conditions of soil or culture or by some injury to its organs, these weak parasites may be able to attack it. Some of the root rots, damping-off troubles and occasional pests of glasshouse crops are familiar examples. However, the greater number of pests and diseases that attack crops from the soil are dependent on the crops they attack, and most of them can only survive for a limited (but often quite long) period in the soil, whether in an active or resting state.

Some pests and diseases of glasshouse crops are thus seen to be natural inhabitants of the soil, but most of them enter glasshouses either by accident, invasion or introduction on infected materials from outside. Under glasshouse conditions, cultivation is intense, the soil is heavily manured and watered, the temperature is relatively high, and the same kind of crop may be grown year after year. These conditions provide special opportunities on the one hand for the introduction and build-up of infection and for unfavourable changes in soil population, and on the other hand for adverse effects on the structure and fertility of the soil. Thus glasshouse soils under continuous cropping tend in time to become "sick" and less productive.

In dealing with this situation, the grower has two problems to contend with: the maintenance or restoration of satisfactory soil conditions, and the destruction of the organisms that attack the crops.

Soil improvement is outside the scope of this bulletin, but it should be observed that satisfactory soil conditions are so bound up with the other problem that measures of improvement, such as the addition of straw, peat or similar materials and attention to problems of manuring, watering, soil drainage and other matters of crop management, are very important.

Effects of Soil Sterilization

Soil sterilization is a means of destroying pests and diseases in the soil. In the sterilizing of glasshouse borders the ground is either prepared beforehand, or dug as the work proceeds, and then sterilized either by steaming or by soaking with a chemical agent. Composts for seed-raising and growing plants in pots and on benches should also be free from soil diseases, pests and weeds; under proper conditions of hygiene some of the ingredients are safe to use, but the loam is always suspect, and it should be sterilized by heating, especially steaming, or by chemical methods.

Heat Sterilization

In the soil all life, including resting stages, is killed at about 260°F, which is, of course, well above the temperature of soil steaming. Below this temperature, the wide range of living organisms in the soil, both beneficial and harmful, are not equally sensitive to heat and some are more easily killed than others. For example, earthworms, eelworms, and the beneficial nitrifying bacteria are killed at about 130°F. Most fungus diseases of glasshouse crops are killed in 10 minutes or less at temperatures between 110° and 145°F, but some wilt diseases have higher thermal death points up to 180°F. A few of the viruses can survive in soil, and some are inactivated at about 130°–140°F, whereas tobacco mosaic is only inactivated at about 190°F.

Many of the useful ammonifying bacteria, which decompose organic matter with the release of ammonia and thus play an essential part in the soil nitrogen cycle, form resting spores which resist steam heat at 212°F for several hours. These bacteria are thus unharmed by the correct use of steam in sterilization, and they multiply rapidly in the soil after steaming, whereas the nitrifying bacteria and others reappear much more slowly. Consequently, large amounts of ammonia are set free which would otherwise be converted into nitrates by nitrifying bacteria or utilized by various organisms.

Ammonia is also released by the partial decomposition of organic matter brought about by steaming. The level of ammonia production is highest in rich soils, particularly if steamed in a wet condition, and is increased by liming the soil.

Injury to young plants and unbalanced growth from excess ammonia may occur, particularly in rich soils, unless steaming is done correctly and under the right conditions, or measures are taken to reduce excess ammonia or to balance it in base manuring. In the preparation of seed and potting composts, the importance of sterilizing the loam separately from other constituents, adding chalk after soil steaming, and balancing the base fertilizers, has been fully established by experiment and confirmed in general commercial practice.

Many of the mineral elements become more available in the soil as a result of steaming. With the major nutrients, such as phosphate and potash, and some other salts, the increased concentration of soluble salts may be a problem in those glasshouse borders in which the salt concentration is too high (low pC) as a result of previous over-manuring or problems of irrigation. With the micro-nutrients, a small increase in availability may soon

lead to excess of the element; for example, manganese toxicity frequently results from the steaming of very acid soils, and these should generally be avoided as sources of loam for compost.

Steaming also results in changes in the colloidal state of the soil organic matter, and steamed soil tends to be more retentive of moisture. It is important that soil for steaming should be as dry as possible and uniformly broken up. Wet soil wastes steam, slows down the sterilizing process, may lead to puddling and damage to soil structure in some parts and inadequate sterilization in others. Soil treatment is only effective if steam reaches all parts of the soil uniformly; otherwise, areas of pest- or disease-infected soil are left behind and rapidly reinfect the clean soil. Incorrect preparation and treatment may, in fact, be worse than useless.

On the other hand, soil baking which was sometimes used in the past for soil sterilization depends upon the soil being wet enough to give off sufficient steam during heating to sterilize the soil effectively. If the soil is too dry, overheating and burning results, organic matter is destroyed, and soil structure, texture and fertility are seriously impaired. The practice has little to recommend it. Even when carefully done, it is an uncertain process and sterilization is likely to be uneven. Some of the soil near the source of heat becomes dry and overheated, while the main bulk tends to be over wet, of poor texture and unsuitable for early use.

Chemical Treatment

In the chemical treatment of the soil two different uses should be distinguished; (*a*) use as soil sterilants, and (*b*) specific treatment for control of particular pests or diseases. The principal materials used at present as soil sterilants are commercial formalin (30–40 per cent formaldehyde) and tar acids. An example of a specific soil treatment is the use of DD emulsion for the control of eelworms.

Formaldehyde, as an alternative to steam, is effective against soil-borne fungi, and is the best available chemical sterilant for controlling soil-borne fungus diseases. Its effect on animal life is limited; it kills the protozoa, but is not generally effective against insect pests or parasitic eelworms under glass. Formaldehyde is stable in the soil; it remains unaltered during normal periods of treatment, but it is gradually lost from the soil by volatilization.

Cresylic acid and other tar acids are effective against some insect and other soil-inhabiting pests, for example, woodlice and millepedes, and give partial control of root knot eelworm but not other eelworms. Tar acids are relatively ineffective against soil-borne fungus diseases. During its passage through the soil, cresylic acid is adsorbed on the soil particles, and the concentration of the solution tends to become diluted at depth.

Carbon bisulphide was used in pioneer work on the partial sterilization of the soil, and more recently it has come into use to control symphilids and also wireworms. It kills the protozoa and also some soil-inhabiting fungi, but it is not as effective as formaldehyde. It has been observed that plants grown in old border soils that have been treated, are usually stronger than those grown in similar but untreated soil. In view of its limited fungicidal properties, and problems in its application, its use is only advised for the control of specific pests.

Chloropicrin, commonly known as tear gas, is being used to some extent for soil sterilization. It is about as effective as formaldehyde in controlling

soil-borne fungi and gives some control of the root knot and potato root eelworms.

Other chemicals are used from time to time for soil treatment, but mainly against specific pests or diseases. They are usually very limited in the range of organisms that they control, and for this reason they are excluded from consideration in this bulletin as soil sterilizing agents.

Hygiene

Soil sterilization is an expensive undertaking, and unless it is done correctly and thoroughly it may well prove worse than useless. Sterilization does not begin or end with soil treatment alone, for traces of infection may lurk in unsuspected places. Before soil preparation is started the structure of the house and its equipment should be thoroughly cleaned down, all debris, used string and plant remains removed for destruction, and the structure disinfected by spraying with formaldehyde or cresylic acid. Propagating houses and potting sheds should have all benches and equipment thoroughly cleaned, special attention being paid to loose scraps of soil on pipes, sills and ledges, and on tools, sieves and similar equipment.

Used soil should never be left about where it may come into contact with clean freshly-sterilized soil, for this can so easily become seriously reinfected. Plant pots and boxes must be clean and free from infection, for recontamination of a well-steamed house or a healthy stock of plants may well result from raising or setting out plants in dirty pots. Furthermore, during the actual operation of steaming or chemical treatment, every care must be taken to avoid treading on soil that has been treated, or allowing any untreated soil or equipment to come in contact with the sterilized soil.

The water supply must be scrupulously clean, and every possible risk of contamination removed. Animal manure also is a potential source of infection, but this risk can be reduced by applying any dung immediately before steaming. In this event, however, some of the valuable physical qualities of the organic matter are lost, the production of ammonia is increased and rank plant growth tends to be encouraged.

Sterilization by Steam

PROPERTIES OF STEAM

Steam is by far the best medium for heating soil for the purpose of sterilizing. It starts as a cheap commodity in the water main, and after evaporation in a boiler travels to the soil and percolates through it under its own pressure; here it gives up heat by condensing in the soil, and adds to the soil moisture already present.

One great advantage of steam over all other methods of heating is that it heats the soil to one fixed temperature, namely the boiling point of water. It so happens that this is safely in excess of what is required to kill the majority of soil-borne pests and diseases but is not high enough to render the soil completely sterile and so damage its fertility. In fact, steaming increases the fertility of the soil in addition to killing recognizable pests and diseases.

The properties of steam and their influence on the steam sterilizing process is briefly dealt with in Appendix III. The important facts to bear in mind are:

1. the steam pressure in the soil cannot be appreciably greater than atmospheric pressure;
2. the boiler pressure is very largely dissipated in overcoming the frictional resistance involved in delivering the steam to the soil;
3. the quantity of heat available for soil sterilizing in one pound of steam (produced from 1 lb water) is 1,000 B.t.u. for practical purposes, and this does not vary with steam pressure.

It follows that the pressure of steam in the boiler is of no significance provided the equipment is suitable for transmitting the output of the boiler at that pressure.

HEATING OF SOIL BY STEAM*

In the steam sterilizing of soil, as usually carried out, the steam is injected into the soil through perforated steel pipes buried horizontally in the loosened soil at a depth of about 12–18 in. A number of such pipes are buried parallel to each other and fed with steam at the same time, so as to steam a plot of soil which should be as nearly square in shape as practical considerations permit. The soil is usually loosened to a depth of 6 in. or more below the pipes as well as above, so that the heat may penetrate downwards to some extent.

Heating Process

When the steam is first turned on, it issues through the holes in the pipes and condenses on the cold soil surrounding them. The heating takes place only by condensation of the steam, and any steam escaping into the atmosphere is wasted.

If the process is carried out efficiently, according to the instructions given later (page 15), the heating of the soil occurs in a progressive manner. The soil immediately surrounding the pipes is first heated to 212°F (the boiling point of water). The steam then passes through this hot soil to heat the cold soil just beyond it. Thus the heating is always occurring in a thin layer or "heat front", often only $\frac{1}{4}$–$\frac{1}{2}$ in. thick, which forms the boundary between hot and cold soil, and for this reason it is not possible to heat the soil to any temperature less than 212°F. If the steam is turned off before the process is complete, part of the soil will be at 212°F, the rest will be cold, and sterilization will be ineffective.

* The principles and practice of the steam sterilization of soil, particularly in relation to the applications of research carried out at the National Institute of Agricultural Engineering, are dealt with more fully in the following reports, published by the National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford.

The Steam Sterilising of Soil. L. G. Morris. *Nat. Inst. Agric. Engin.* C.S. 14/1170.

The Steam Sterilising of Soil — Application of Research to Practice. L. G. Morris. *Nat. Inst. Agric. Engin. Rep. 24.*

Some Experiments on the Steam Sterilising of Soil. L. G. Morris & K. W. Winspear. *J. Agric. Engin. Res.* **2**, 262.

The Steam Sterilisation of Glasshouse Soils. L. G. Morris. Rep. 14th Internat. Hort. Cong. (1955) **1**, 634.

The manner in which the heat travels through the soil is shown diagrammatically in Fig. 1. The perforated pipes are usually laid side by side in the soil at a spacing of 15–18 in. The heat from each pipe spreads out radially at first and steam is continually passing through the hot soil from the pipe to the heat front, where it condenses on the soil being heated. The hot soil naturally contains steam in its spaces instead of air, the latter having been driven out of the soil ahead of the heat front. The heat front from each pipe, after spreading out radially, meets and fuses with the fronts from the adjacent pipes to form a single horizontal but rather undulating front which then rises to the soil surface. The surface directly above the pipes heats up first and that midway between the pipes last. During this time all the loose soil below the pipes should also have become hot, but the penetration of heat into the undisturbed soil below is very slight indeed—only a fraction of an inch.

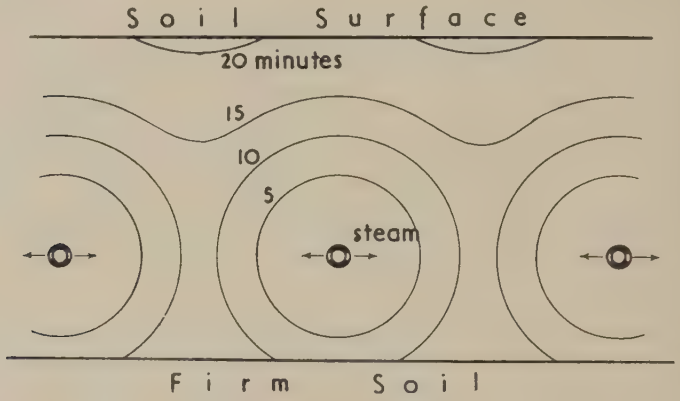


Fig. 1. Heat travel through soil

Soil Uniformity

In practice, inequalities in the soil may cause deviations from this pattern of heat flow. The passage of heat downwards is not usually quite so rapid as it is in the upward direction. This depends on how well the soil is broken up below the pipes and whether the air can escape easily, but it is a safe rule to assume that the heat will travel 6 in. downwards in loose soil below the pipes for every foot of soil above them.

Provided the soil is well prepared with at least 2 in. of fine soil at the surface, it will not matter if there are a few unbroken clods here and there below, as these will be sterilized by the bulk of hot soil round them. The penetration of heat into a hard clod of soil is very slight at first. What happens is that the heat front travels past the clod at undiminished speed, heating its surface to boiling point in passing. Thus by the time the steam is turned off, the clod may still be mainly cold but with a hot surface and surrounded by hot soil. Given a good soil cover, the clod continues to heat up slowly by conduction of heat from its hot surface and the surrounding soil until eventually the clod is sterilized right to its centre. In this way a hard ball of soil as much as 7 in. in diameter has been found to become sterilized all through in the course of 1–2 hr.

Rate of Steaming

The thickness of the heat front depends on the rate at which steam is supplied and on the nature of the soil, because steam can only condense at a certain rate on a given surface area of soil particles. The optimum rate of steam injection is about 18 lb/hr per sq. ft of plot, and at higher rates the wastage of steam increases and becomes extremely wasteful at 25 lb/hr per sq. ft. When the rate of steam supply is increased, the heat front requires a greater surface area of soil particles for condensation and so the front is thicker. If the soil is more lumpy the front must again be thicker to offer the same area for condensation.

Furthermore, at high steaming rates, steam pressure tends to build up in the soil. The weight of the foot depth of soil is only sufficient to balance about $\frac{1}{2}$ p.s.i. of steam pressure, so that at high rates of steam flow it is quite easy for the steam to relieve the pressure by bursting through to the surface in several places. Once this has happened steam blows through the blow holes, as they are usually called, until the cook is completed. The escape of steam may be too fast to be contained by a covering sheet and much steam may be wasted in this way.

Blow holes have a greater tendency to appear in dry dusty soils and in soils which are non-uniform as regards moisture or lumpiness. The non-uniform soils are always difficult to steam efficiently, but a dry dusty soil can be steamed perfectly well if the rate of steam flow is kept low enough. Thus, to avoid wastage of steam through blow holes a sufficiently slow rate of steaming is essential.

Spacing of Pipes

Another source of inefficiency in steaming is due to wide spacing of the pipes. The heat front which rises to the surface has a wavy or corrugated shape, being highest immediately above the pipes and lowest midway between them. As a result the soil surface above the pipes becomes hot first and steam blows through to waste until the rest of the surface is hot and the steam is turned off. The wider the spacing of the pipes, the more serious this effect is, and, in general, the spacing should not exceed $1\frac{1}{4}$ times the depth of the pipes below the surface.

Covering the Soil

The complete heating of all the soil down to the required depth is most important, since any local unsterilized portions may form centres of infection which start to spread through the soil after it has cooled. Since the surface of the soil is the last part to become hot, this is where there is a danger of leaving small areas unsterilized, and some form of covering over the soil is essential to guard against this.

The best type of covering is one which spreads the escaping steam, so that steam, lost through parts of the surface which are already hot, is trapped and condenses on the cold surface elsewhere. Canvas and tarpaulin have been used in the past, but they are being replaced by thin plastic sheets.

Plastic sheets are lighter to handle than canvas or tarpaulin and are much more effective in spreading steam. A further advantage of plastic is that it indicates clearly when the soil surface is hot, and the steam cannot condense any more, by raising the sheet to form a "balloon" about a foot clear of the ground. The balloon first forms over the hot patches of the soil and as the

heat spreads over the surface, so the balloon spreads until the whole surface is hot. Thus it is easy to detect the right moment to shut off the steam and so prevent waste.

To function satisfactorily, the plastic sheet must be used in the right way. It should be spread smoothly over the soil with no folds and the edges must be weighted down with lengths of iron chain (e.g., ventilator chain) which will follow the contour of the ground. Plastic sheets have a short life, but the cost is not high and the saving in fuel makes their use well worth while.

At present, polyvinyl chloride (P.V.C.) about 0·008 in. thick and specially formulated for this application is most satisfactory. Sheets, 9 × 6 ft, seamed at the edges to take chain, have a reasonably long life. Rayon impregnated with P.V.C. can also be used; it has a longer life, but is much more expensive. Doubtless, other useful materials will be forthcoming in course of time (see Plate I).

Peat is a good heat insulator and being sterile it need not be heated itself. If it is intended to use peat as a soil conditioner, it is a good plan to put it on top of the soil before the steaming process starts and provided the layer is deep enough (not less than 2 in.) no other covering should be necessary.

Steam Losses

The use of a good covering turns the escape of steam through the surface to good account by spreading it over the remaining cold surface, but a slow enough rate of steam injection will prevent excessive losses in this way.

There is, however, another loss of steam which is more difficult to control, namely the escape of steam round the perimeter of the plot being steamed. Steam escaping in this way may travel into the hot soil steamed in the previous cook, in which case it passes through it and escapes through the surface. On the other side of the plot it may travel into cold soil and condense, in which case the soil will eventually be heated twice. In either case there is waste, and the best way to reduce it is to sterilize larger plots at a time and so reduce the number of "overlaps" in the width and length of the glasshouse. It is best to have the plot as nearly square as possible, the need to inject steam sufficiently slowly, i.e., not more than 18 lb/sq.ft/hr, also leads to the use of larger plots than are usually steamed for a given size of boiler. It is also an advantage for each cook to be done at the same rate, regardless of the length of the steam main.

Matching Plot Size to Boiler Output

In order to steam the soil efficiently with the minimum of fuel, it is essential to match the size of the plot steamed at a time to the rate at which steam can be supplied. This is usually the full output of the boiler, but where it is impracticable to steam such a large area at a time, the correct rate of flow can be obtained by control of steam pressure. For example, with a steam output of 1,000 lb/hr the minimum size of plot to be steamed at one time would be 56–60 sq. ft, and with a 1,500 lb/hr boiler about 84–90 sq. ft (see Table 1 for other values). This is one of the most important factors affecting steam economy during soil sterilization.*

* See also John Innes Leaflet No. 14 (1955). *Balanced Steaming of Glasshouse Soil.* Oliver & Boyd, Edinburgh. Price 1*s*.

TABLE 1

Minimum Steaming Area in relation to Boiler Output

Boiler output		*Recommended minimum steaming area*	*Total length of Hoddesdon pipe required*	
			Spaced 18 in.	*Spaced 15 in.*
lb/hr	*lb/min*	*sq. ft*	*ft*	*ft*
400	6·6	22	15	18
600	10·0	33	22	26
800	13·3	44	29	35
1,000	16·6	56	37	45
1,500	25·0	84	56	67
2,000	33·3	112	75	90

If the full output of steam is used in this way, the duration of each cook should usually be 1½–2 min for each inch of depth of loose soil. This requirement results in a plot of larger size than has been customary in the past and it is often convenient to use long perforated pipes (see page 16) or long spiked pipes in order to cover the area with the most effective layout of pipes. Increasing the plot area to an efficient size does not affect the amount of labour required for digging, as this would depend primarily on the area of glasshouses to be steamed.

HEAT CAPACITY AND SOIL MOISTURE

Apart from the efficiency with which the steam is generated and delivered to the soil, the amount of fuel required to sterilize a given quantity of soil depends fundamentally on the heat capacity of the soil, which is measured as the amount of heat required to raise the temperature of one cubic foot of soil through 1°F. The heat requirements of different soils can therefore be compared by referring to Fig. 2, which shows, for three types of soil, how the heat capacity depends on the soil moisture content, over the extreme range of conditions likely to be encountered. The heat capacity in this diagram is based on a cubic foot of firm, not loosened, soil.

Owing to the fact that water absorbs 4–5 times the amount of heat per unit weight that dry soil does for the same temperature rise, the heat capacity of soil increases rapidly with an increase in moisture content. It will be seen that, at both the dry and wet extremes, the heavy soil contains more than twice as much moisture as the light soil, but this is partially offset by the greater density of light soil, and when both soils are dry, the heavy soil has only slightly the greater heat capacity. The addition of moisture up to the wet condition, however, doubles the heat capacity of the heavy soil (100 per cent increase) while for the light soil the increase is only 50 per cent.

A peat soil is similar to a heavy soil in having a wide range of moisture content and therefore of heat capacity.

In order to economize in fuel, it is most important to keep the soil as dry as possible before sterilizing, particularly if it is heavy or of a peaty nature. The most effective way to dry the soil is to leave plants in the soil without water for a few weeks before clearing the house, and this should be done where possible. Otherwise probably the most that can be done is to avoid wetting the soil unnecessarily, particularly from leaks under gutters

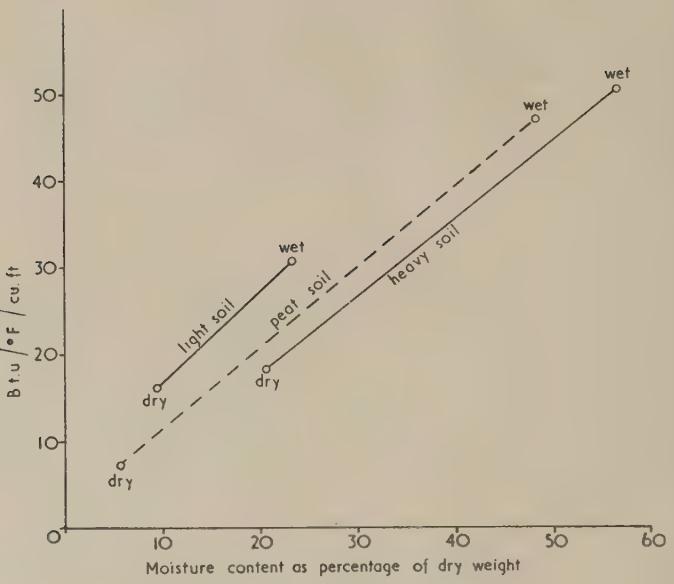


Fig. 2. Heat capacity and soil moisture

or elsewhere, which are often a source of trouble because of ineffective sterilization of the wetter patches.

Summary of Points in Steaming

1. When soil is steam sterilized its final temperature is the boiling point of water, 212°F. It cannot be greater or less than this.
2. The heating takes place in a heat front which travels progressively from the pipes to the soil surface, which is the last part of the soil to become hot.
3. The steam will penetrate 6 in. below the pipes for every foot of soil above them, provided the soil is broken up. Steam will not penetrate hard soil.
4. Lumps of soil 2 in. or more below the surface eventually become sterilized by heat conduction from the surrounding soil, but the top 2 in. of soil must be well broken.
5. The best rate of steaming is about 18 lb/sq.ft/hr; higher rates waste steam.
6. For uniform heating the pipe spacing should not exceed $1\frac{1}{4}$ times the depth of the pipes.
7. The soil should be covered during steaming to spread escaping steam over the surface. A thin plastic sheet indicates when the soil is hot by rising to form a balloon, if the sheet is held down round its edges.
8. Steam should be turned off as soon as the entire surface is hot.
9. The size of plot to be steamed should be matched to the steam supply. With a steam supply of 1,000 lb/hr, the minimum size of plot to be

steamed at a time should be 56–60 sq. ft and *pro rata* (i.e., for each 100 gal/hr water evaporated). It does not matter if the plot area is larger than this minimum size, but it should not be appreciably smaller.

10. Fuel consumption increases rapidly with increase in soil moisture. Keep the soil dry before starting, particularly with heavy and organic soils, and avoid wet patches where possible.

BOILERS AND STEAM PRODUCTION

Steam is normally generated by boiling water in a vessel, which may either be closed or open to the atmosphere. Both types of generator are used to produce steam for soil sterilization, but the use of the open type is limited to the treatment of small quantities of soil for making up seed and potting composts. For sterilizing soil in glasshouse borders, or in large quantities for potting, steam must be generated under pressure.

Boilers

Boiler Capacity

The capacity of a steam boiler is measured in terms of the weight of water it will evaporate per hour when working at full output. A horse-power figure is sometimes given, but it is misleading and bears no direct relationship to the work in hand. If the capacity of a boiler is not known, it can be ascertained approximately with a loco-boiler in either of the following ways. The quantity of feed water injected in a given time may be measured when the boiler is on full load and at constant water level. Alternatively, an estimate can be made assuming a rate of burning of 15 lb of coal per sq. ft of grate area per hour and a rate of evaporation of 7 lb water per lb of coal burned; thus a loco-boiler with a good 20–30 ft chimney should evaporate $15 \times 7 = 105$ lb water per sq. ft of grate area per hour.

Boilers for this work are of two types: (*a*) low-pressure boilers working at pressure up to about 25 lb/sq. in.; (*b*) medium-pressure boilers working at pressures up to about 120 lb/sq. in.

Boiler Pressure

There is no single ideal boiler pressure for steam sterilization. It can have any value between 5 and 150 lb/sq. in. and provided the equipment for passing the steam into the soil is suited to the pressure and output of the boiler, pressure itself is not of major importance.

Low-pressure Boilers. With the increasing use of low-pressure steam for heating, more low-pressure boilers are being used to produce steam for soil sterilization. Some steam boilers can also be used for hot water heating. This method may save the cost of a separate sterilizing boiler, and is particularly suitable where a new boiler is being installed.

Portable low-pressure steam boilers are not manufactured in this country at present. Some have, however, been imported from the Continent during the past few years, and are working satisfactorily.

There is also the possibility of operating medium-pressure boilers at greatly reduced pressure when they are too old to be insured at their original pressure. It must be remembered that large diameter mains must be used with low-pressure steam in order to get the necessary rate of transmission.

Medium-pressure Boilers. Any type of medium-pressure boiler can be used to generate steam for soil sterilization. These may be either fixed boilers or portable loco-boilers (see Horticultural Machinery Leaflet 2: *Boilers for Nursery Use*).*

Portable loco-boilers are the most commonly used. Small vertical cross-tube boilers are often fitted for sterilizing soil in bins, but the other fixed types are only used when they are already fitted for generating steam for heating.

Adaptation of Existing Equipment

The cost of new equipment is often prohibitive for small growers and they are, to a large extent, dependent upon hire services. Much can be done, however, often with little expense, to adapt secondhand equipment. Steam traction, ploughing and other portable self-contained steam engines can often be purchased quite cheaply. Conversion normally entails removal of the cylinders and other motive gear and the fitting of a steam take-off; it should, however, only be considered when the boiler is in good condition and has a reasonable life left without major overhaul. The output of such boilers is lower than when they are used as engines, as the draught is greatly increased by the exhaust steam from the engine. For steam sterilizing the draught can be augmented, preferably by a forced draught fan (see below) or by a steam jet blower at the chimney base, but this is very wasteful.

Small portable boilers, such as the steam "Jenny" often used for generating steam for cleaning stonework, etc., can sometimes be bought cheaply, but the steam produced by these generators is normally very wet. Provided they can be adapted to produce dry steam by fitting a suitable separator, they can be used for steaming soil for composts, but their output of steam is far too small for steaming border soil.

Smoke Control

Attention is drawn to the requirements of the Clean Air Act, 1956. The Act aims at preventing atmospheric pollution by smoke and gritty particles emitted in smoke. Its provisions affect glasshouse growers and nurserymen by the establishment of smoke control areas, by control of the installation of new boilers and furnaces, and by control of the emission of dark smoke from heating and steam sterilizing boilers. From 1 June, 1958, with certain limited exceptions, it is an offence to emit dark smoke from any chimney.

The Ministry of Agriculture has issued a free leaflet, which explains how growers are likely to be affected and where they need to take action, but it is not a legal exposition of the requirements of the Act. The special problems of loco-type steam boilers, and the action that growers and contractors need to take are dealt with fully in the leaflet.†

Forced Draught

For increasing draught by means of a fan, the ashpit must be sealed, and a small draught fan fitted so that air can be blown into the closed space beneath the fire base. The fan may be driven by an electric motor or, where

* Single copies free from Ministry of Agriculture (Publications), Soho Square, London, W.1.

† *Smoke Control: What glasshouse growers have to do under the Clean Air Act.* Obtainable *free* on application to the Ministry of Agriculture (Publications), Soho Square, London, W.1.

power is not available, by a small petrol engine and vee-belt drive. The power consumption of the fan need not exceed 1 h.p. and the speed is usually 1,330–1,600 rev/min. The size of fan required for a given evaporation can be ascertained by allowing 250 cu. ft of air per 1 lb of fuel burned and an evaporation of 7 lb water per lb of fuel. Thus, for example, a boiler that could evaporate 2,100 lb water per hour would consume:

$$\frac{2{,}100}{7} = 300 \text{ lb fuel/hour}$$

$$\text{Air required per minute} = \frac{300 \times 250}{60} = 1{,}250 \text{ cu. ft per min}$$

The air pressure under the grate would vary with the fuel and condition of the fire, but to allow a margin of reserve the fan should be capable of delivering the *maximum* quantity of air needed for full boiler output at a pressure of $1\frac{1}{2}$ in. water gauge in the ashpit. It is essential that a butterfly damper should be fitted into the air duct and the control handle taken to such a position that it can easily be moved by the fireman.

The fire bars supplied with natural draught furnaces are not suitable for forced draught, as the air spaces are too wide. Forced draught grates should have air spaces of $\frac{1}{8}$–$\frac{3}{16}$ in. width, and the free air space should be about 16 per cent of the grate surface. A depth of 4–5 in. would give ample strength and provide enough air-cooled surface to keep the fire bars cool even with poor fuels.

Heat Conservation

The conservation of heat is just as important as efficient steam generation and particular attention should be given to the lagging of all steam-heated surfaces and fittings such as valves and flanges. As exposure to wind greatly increases the rate of heat loss from hot surfaces, it is preferable for the steam boiler to be in a building or to have some temporary structure arranged around it.

Boiler Operation

When starting up, the boiler is normally filled through the filler plug-hole in the main inspection cover. When the correct level is reached, as shown by the gauge glass, the filler plug is inserted, screwed down and the fire then lit.

During operation, the water level is maintained by the action of a steam- or mechanical-pump or by the use of a steam injector. Where pumps are used, they should be drained in frosty weather.

With injectors it is necessary to maintain a boiler pressure of at least 60 p.s.i. if they are to operate satisfactorily. All joints and unions should be air- and steam-tight, and the injector kept cool; otherwise it will not work, nor will it lift warm feed water.

Routine. The following points in operation should be strictly observed:

1. The water in the gauge glass must be maintained at the correct level. The gauge glass should be blown out daily, and if no action is seen in it when the boiler is at work, a test for stoppage should be made.
2. A suitable boiler fluid must be added to the feed water at the correct times and in the right quantities. No water should be allowed to enter the boiler until it has been treated (see also page 14).

3. The boiler should be blown down one inch as registered by the gauge glass daily, when it is more or less at rest, i.e., lunch hour or evening. By this means the water density is lowered, and steam raising is much easier. Care is needed in performing this task: (*a*) open the cocks to get a steady flow out of the boiler; (*b*) when closing cocks, swing them full open at first and then close, in order to clear out any hard matter and so avoid damage to the cock when closed.
4. Gauge-protecting glasses should be kept on when the boiler is under pressure.
5. Steam should be turned on gradually to warm up the pipe line and blow out condensate.
6. Keep the water above the safety level.
7. Boiler tubes and smoke box should be brushed out and thoroughly cleaned at least once every 12 hr during use. Accumulation of dust and other debris causes the surface of the metal to deteriorate, if in contact with it too long, and dirty tubes reduce efficiency.

Fuel. The most satisfactory fuel for steam production is the best Welsh steam coal (smokeless) but a good hard coke can be used provided the bars of the fire-box are $\frac{3}{4}$–1 in. wide, and set $\frac{5}{8}$–$\frac{3}{4}$ in. apart. Where coke is favoured, it is generally preferable to start the fire in the morning with steam coal and then carry on with coke for the rest of the day, because steam coal develops a head of steam quicker than coke. Where low-grade (high volatile) fuels have to be used, secondary air should be admitted by fixing a shutter on the door of the fire-box, otherwise combustion will be incomplete with consequent excess of smoke (see also Forced Draught, page 12).

Stoking. The efficiency of steam production is almost entirely in the hands of the boilerman. Given a suitable boiler and fuel, a good stoker will give the workmen all the steam they require and will economize on fuel consumption. A shallow, bright fire, maintained the whole time gives the best results, the actual fire depth depending on the size and kind of fuel used. A skilful stoker replenishes with fuel a little at a time, filling up the hollow spaces in the fire and maintaining a well-packed bed of fire with a dish-shaped surface, the depth being greatest round the well of the furnace. The centre of the fire should not be allowed to get too thin, or blow-holes result. In the case of bituminous coal the thickness should be about 4 in. for singles, and about 8 in. for 4 in. cubes. With anthracite and low volatile coal, the thinner the fire that can be maintained without blow-holes, the better.*

Water Treatment. All boiler feedwater should be treated to minimize scale formation and corrosion. A number of firms specialize in this type of work. They will analyse water supplies and give recommendations for treatment. Treatment is simple and normally entails adding a mixture of chemicals to the feedwater. The expense is well worth while and is more than saved in maintenance repairs.

Boiler Safety. A satisfactory procedure for protection against the liability of injury or damage from burst boilers is to insure against explosion risk with

* Further details on use and care of boilers are given in *The Stokers Manual.* Published by the National Industrial Fuel Efficiency Service, 71 Grosvenor Street, London, W.1. Price 2*s.* 6*d.* (including postage).

one of the insurance companies specializing in this class of business. The annual premium includes the inspection fee for engineers employed by the company and who are regarded as competent by the Board of Trade.

At the end of each sterilizing season, a steam boiler should be thoroughly overhauled and reconditioned. It must undergo an internal and external inspection and a steam pressure test by a boiler surveyor before re-insurance in accordance with Board of Trade regulations.

METHODS OF SOIL STEAMING

As has been shown in the preceding chapter, the sterilization of soil by steam is effected by passing steam into the bulk of soil. In its passage through the soil the steam condenses to water, giving up its latent heat. This heat gradually raises the temperature of soil to 212°F, after which the bulk of the steam escapes into the air. Only steam condensed in the soil does useful work in sterilizing, and for efficient working the escape of live steam into the air should be reduced to a minimum.

Several methods of soil steaming are in use at the present time, but whichever method of injecting steam is used the basic requirements are as follows:

(*a*) The depth of injection should be sufficient to ensure complete heating of all the loosened soil (i.e., at least two-thirds of the total depth of the loosened soil).

(*b*) The injection should be sufficiently uniform to ensure that all the surface soil becomes hot at about the same time.

(*c*) The area of soil steamed at a time should be matched to the boiler output. The plot should be about 84–90 sq. ft, for a 1,500 lb/hr boiler and *pro rata* for other sizes.

If these requirements are met, the efficiency of the steaming process is not affected by the method used. The method is mainly governed by consideration of economy in man-power, labour limitations, the size and design of the glasshouse, and depth of sterilizing desired.

In practice, the steam is injected into the soil through small holes in the walls of steel pipes, the rate of flow depending on the total area of the holes and on the difference in pressure inside and outside the pipes. As the pressure of the steam outside the pipe cannot exceed the atmospheric pressure appreciably, the difference in pressure is in effect equal to the pressure in the pipe.

Methods using Buried Perforated Pipes

Hoddesdon Pipes

This is the method in most common use. They are steel pipes, generally 6–7 ft long and 1 in. to 1¼ in. internal diameter, which are laid horizontally in the soil at a depth of 12–18 in. below the surface and at a spacing, side by side, of the same distance or a little more. They are each closed at one end and fed with steam at the other end through vertical pipes, 2 ft long and of the same diameter. This vertical pipe is connected to the horizontal one by means of a bend or elbow and carries another bend at the top for the steam connection. The steam passes into the soil through perforations

which usually consist of pairs of $\frac{1}{8}$ in. holes at a spacing of about 5 in. along the whole length of the horizontal pipe (see Fig. 3). There is usually also an additional hole in the underside of the pipe at the closed end through which condensed water can escape.

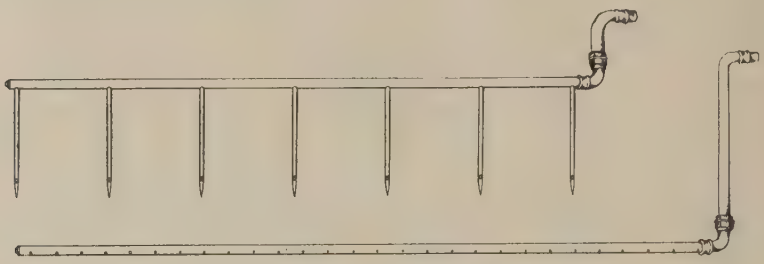


Fig. 3. Hoddesdon pipe and spiked pipe.

A number of these pipes are used side by side according to the plot area to be steamed. The soil has to be moved in order to place the pipes in position; thus the digging of the borders is effected as the work proceeds. For the first pipe a trench is opened alongside the wall, the bottom of the trench is well broken up and the pipe placed in position. This is then covered with soil from the next trench which is opened alongside for another pipe; and so on until all the pipes are in place (see page 25 for details of operation).

This is the most thorough method of steaming, and the only method of really deep steaming — a depth of 18 in. being possible with forking of the bottom of the trench. The use of separate pipes gives flexibility to the method in dealing with obstructions and provides thorough coverage in steaming the borders. Preparation and laying is, however, laborious and costly, and the method offers no scope for machine operation.

The area to be steamed at one time and therefore the number and length of pipes to be used should be governed by the steam supply or output of the boiler (if this is fully used) and the width of the houses. For example, with a house 18 ft wide and a boiler output of 1,000 lb/steam per hour, the steaming area should be about 60 sq. ft (see Table 1 on page 9) and this could be conveniently done by means of 6 standard 7 ft Hoddesdon pipes spaced 18 in. apart,* which would cover half the width of the house. It should be recognized, however, that it is often impracticable to get a good fit with standard Hoddesdon pipes, and it may be worth while to use longer ones to match the steam supply and house shape better.

Long Pipes

Although it has been customary for Hoddesdon pipes to be normally limited to a length of about 7 ft, it is quite possible to use similar perforated pipes up to a length of 16 ft. Long pipes are commonly used on the Continent and have been tested in sandy loam in this country. It was found that the soil was steamed very satisfactorily and the withdrawal of the pipes after steaming, which was the crucial part of the test, was performed by one man

* The spacing of the pipes, however, depends on the depth at which they are to be set, and their distance apart should not exceed $1\frac{1}{2}$ times the depth; thus pipes spaced 18 in. apart would have to be set about 15 in. deep at least (see also page 7).

without undue effort. The ease of withdrawing the pipes and their useful life are both improved if galvanized pipe is used in their manufacture.

The main advantage of long pipes over normal Hoddesdon pipes is that larger areas of soil may be steamed at a time, without using an inconvenient number of pipes. It is also possible to design their number and length so as to get the most convenient plot size and shape to match the steam supply and the width and length of the houses on the particular holding.

The diameter of the perforated pipes must be sufficient to give reasonable strength and rigidity and also to ensure uniform steaming along the length of the pipe. If the size is too small, the holes at one end tend to deliver more steam than at the other end, but this may be avoided by using a pipe the cross-sectional area of which is 1½ to 2 times the total area of the holes. Adequate strength and uniform steaming are usually obtained if 1 in. internal diameter is used for pipes up to 9 ft long and 1¼ in. diameter for longer pipes.

Grid Method

This method is still in use, but, in general, it has been superseded by the Hoddesdon pipe (but see plough-type grids below). There are usually four perforated pipes 4 or 5 ft long and 1 in. internal diameter, which are held parallel to each other and at the required spacing by a transverse pipe of a larger size which joins them at one end. Steam is delivered through a single vertical pipe to the transverse pipe and thence to the perforated pipes. Each grid thus sterilizes an area of about 16–25 sq. ft.

The grid method has several disadvantages. Both the digging and the handling of the grids are more laborious and for this reason larger grids than those described are impracticable. It is also difficult to cope with obstructions such as purlin posts and heating pipes. One small advantage is that it is easier to ensure that the bottom soil is well loosened.

One variation of the grid consists of two pipes about 7 ft long, rather like a double Hoddesdon pipe and with some of the advantages of both methods. When covering the pipes the soil is thrown from the side, thus thorough digging can be done without much increase in labour. The two pipes stand upright themselves and need not be held while the soil is placed on them as has to be done with single pipes. With these double pipes it is not possible to vary the spacing between them and it is usually necessary to have one or two single pipes in addition to deal with the soil near obstructions.

Plough-type Grid: Mechanized Steaming

Efficiency of steam utilization is only half the problem of reducing the cost of steaming and attention has recently been directed to improving the efficiency of labour utilization by mechanizing the steaming process. Plough-type steaming grids have been in use in Denmark and some other Scandinavian countries for several years, and similar equipment has now been put on the market in this country.

The plough-type grid is essentially a series of Hoddesdon pipes coupled together and fixed to a rigid frame. This frame is buried in the soil at one end of the glasshouse and hauled through the soil by a winch, steam being supplied continuously through a long flexible hose. The equipment and boiler can be worked by one man with some assistance in changing over at

the ends of the houses. Before steaming commences, the soil is rotary cultivated to enable the grid to be drawn through, but it should be realized that sterilization is only effected to the depth of cultivation.

The standard unit consists of four pipes about 7 ft long covering a bed 4 ft wide, though extensions can be fitted to each side giving a total of six pipes covering a 6 ft width, if this is desired. The grids can be lengthened to about 9 ft 6 in. by fitting extension pieces at the rear end of each perforated pipe. The rate of steam supply should still be about 18 lb/sq.ft/hr, despite the fact that the grid is moving through the soil. The speed of travel has to be adjusted, so that the soil is sterilized but without wasting steam. This can be done by means of a variable speed gear on the winch. The normal variation is between a maximum speed of about 1 ft per minute and a minimum speed of about 8 in. per min. Two grid units and the winch form a working unit, complete with hose and tarpaulin sheeting.

This unit has been tested at Fairfield Experimental Horticulture Station, and temperature surveys were carried out during the steaming process. It gives very efficient sterilization down to a depth of 13 in. and takes about 16 hr to sterilize a glasshouse 150 × 15 ft in four hauls. With most boilers, it is necessary to control the rate of steam flow to avoid wastage as the steam requirement given above is well below the output of most loco-boilers used for steaming on nurseries. With this particular unit, the working rate can only be increased by multiplying the number of basic working units, though there seems no reason why units for larger scale working should not be developed.

Land Drains

The passing of steam into the soil through land drains has been widely practised in the United States and by some growers in this country.

Methods using Spikes

Spiked Pipes

In this method steam is injected into the soil through short vertical pipes or spikes (Fig. 3). These are small diameter tubes, closed at the lower end and pointed to facilitate entry into the soil. The steam passes into the soil through 2–4 holes of $\frac{1}{8}$ in. diameter, drilled about 1 in. from the pointed end and at a depth below the soil surface of 9–12 in. At the point where the holes are drilled, the spike should be necked so as to reduce blockage of the holes with soil as much as possible. Spikes of $\frac{1}{2}$–$\frac{3}{4}$ in. internal diameter are attached to a horizontal pipe which rests on the soil surface when in use and through which steam is fed (see Fig. 3).

The fixed spacing of the spikes along the pipe should be almost equal to the depth of the holes below the surface pipe but not more than 12 in.

As with Hoddesdon-type perforated pipes, the diameter of the horizontal pipes is determined by the total area of holes being supplied with steam, the cross-sectional area of pipe being 1$\frac{1}{2}$-2 times this figure. This results in the horizontal pipe having a diameter of 1 in. if less than 9 ft long, or 1$\frac{1}{4}$ in. diameter if longer.

A spiked pipe is comparable with a single Hoddesdon pipe. The main advantage of spiked pipes over the buried pipe method is that the loosening of the soil can be done by machine, thus saving labour, but the depth of sterilizing is only the depth to which the soil is loosened and this is limited

by the method of cultivation. The buried pipe method must be used for deep sterilizing.

The procedure using the spike method is to dig or rotary cultivate the soil in one operation before steaming is begun. The soil is sterilized in alternate plots as in the Hoddesdon pipe method (see page 16). The spikes are pressed into the loose soil until the horizontal pipe reaches the soil, which is then settled round the spikes by means of a fork to prevent the escape of steam.

The type of soil covering used in conjunction with this method may take several forms. The whole plot may be covered with a sheet or the spaces between the pipes covered with separate strips of material which are wide enough to overlap slightly. In this way the pipes may be withdrawn from the soil before the covering is removed, and there is thus no need to tread on the freshly-sterilized soil.

In order to obtain reasonably uniform heating of the soil, the spacing between the horizontal pipes should not exceed 12 in., or 1½ times the depth of the holes below the soil surface (if this is less). The number and length of pipes may be chosen to suit any desired size and shape of steaming plot. The distribution of steam to spiked pipes is through a header in the same way as with the Hoddesdon type (see page 20).

The equipment should have suitable handles in the right positions for easy manipulation.

Spiked Harrow

This method, now little used, consists of several spiked pipes joined together in a rectangular framework fed by a single flexible steam hose. They are difficult to handle except in small sizes, and obstacles cannot be readily negotiated. They have none of the flexibility in use that is possible with the spiked pipe and the Hoddesdon-type perforated pipe.

Steaming from the Surface Downwards

Tray Method

This system has been out of favour for some years, and is now only used by a few growers. It employs an inverted rectangular pan or tray, the sides of which are pressed into the soil. Steam is admitted beneath the pan at a very low pressure and heating takes place from the surface downwards. The depth of sterilizing depends on the depth of cultivation and on the duration of the cook. It can be used for sterilizing the top 3–6 in. of soil in frames, but it tends to be wasteful of fuel. Its chief promise lies in quick steaming of surface soil in frames to kill weeds and weed seeds.

Plastic Sheet

A similar method is being used to some extent for sterilizing the soil in forcing and propagating frames, and in raised carnation beds. A thin plastic sheet is spread over the whole length of the bed and steam is admitted under the sheet through a canvas hose or a perforated steel pipe; the steam leakage through the canvas or the holes in the pipe giving a uniform distribution of steam. Condensation on the sheet seals it to the sides of the bed and heating takes place downwards at a slow rate of about 6 in. in 2 hrs. Since air is denser than steam, sterilization is only efficient if the air can escape through drainage holes in the bottom of the bed.

The Methods Summed Up

For deep sterilizing at a total depth of 12–24 in., the buried perforated pipe method is the only possibility. With single pipes, either Hoddesdons or longer pipes, it is easy to make the plot size match the output of the boiler and to fit in with the glasshouse width. It is also easier to sterilize the soil surrounding obstacles by using single pipes.

The spiked pipe is labour saving for sterilizing to the depth of rotary cultivation, say up to about 9 in. Grids and spiked harrows are generally cumbersome, difficult to handle and to negotiate obstacles and they lack the flexibility in use of the single pipe units.

Methods of steaming from the surface downwards are useful in raised beds, and where only the top few inches of soil need be sterilized for weed control in frames.

In deciding on the type of equipment to use, it is of first importance that it should be flexible in use; to permit thorough and workmanlike cover of the area. If it is reasonably easy to handle, work can proceed steadily with some economy of labour. The development of equipment for mechanizing steaming work promises to reduce the cost as well as to lighten the heavy work at present involved in steaming glasshouse soils, but the depth of sterilization is limited by the depth of cultivation.

Steam Distribution to Pipes

Distributors

Steam is supplied through some form of rigid main, running from the boiler, and then through a length of flexible pipe to a distributor, which divides the steam supply equally to all the pipes in use, whether Hoddesdon type or spiked pipes. Distribution may be by means of a steam chamber (or header) to which the required number of exit pipes are connected, or by suitable Y-pieces or breeches dividing a single pipe first into two and then into four or six branches.

With the steam chamber, the steam issues through a number of exit pipes corresponding to the number of pipes in use, but seldom exceeding six. Some steam chambers are heavy and cumbersome to use, and the Y-distributors are more convenient to handle under working conditions.

A convenient Y-distributor for four Hoddesdon pipes consists of three Y-pieces joined together by screw collars (Fig. 4 (*a*)). Where six pipes are in use, two three-way distributors, each connected to a main Y-piece, would be needed (Fig. 4 (*b*)). If eight pipes are wanted, two four-way distributors could be connected by flexible hose to a Y-piece of at least 2 in. diameter. Alternatively, two-way distributors can be used throughout (Fig. 4(*c*)). If a reducing valve is in use, the steam supply delivered through a 3 in. pipe from the valve would first be breached into 2 in. branches (Fig. 4(*d*)).

The diameter of the pipes after the main must be related to that of the main itself, to allow an unrestricted flow of steam. For example, with eight Hoddesdon pipes working from a 2 in. main, the main is breached into two $1\frac{1}{2}$ in. sections, each carrying a $1\frac{1}{2}$ in. flexible. Each section is connected to a $1\frac{1}{2} \times 1\frac{1}{4}$ in. Y-piece, each $1\frac{1}{4}$ in. branch of which is then split into two 1 in. connections, giving four 1 in. inlets to the Hoddesdon pipes (Fig. 4(*c*)).

From the distributor, the steam is fed to the pipes through lengths of flexible rubber hose usually about 5 ft long, which are connected to the

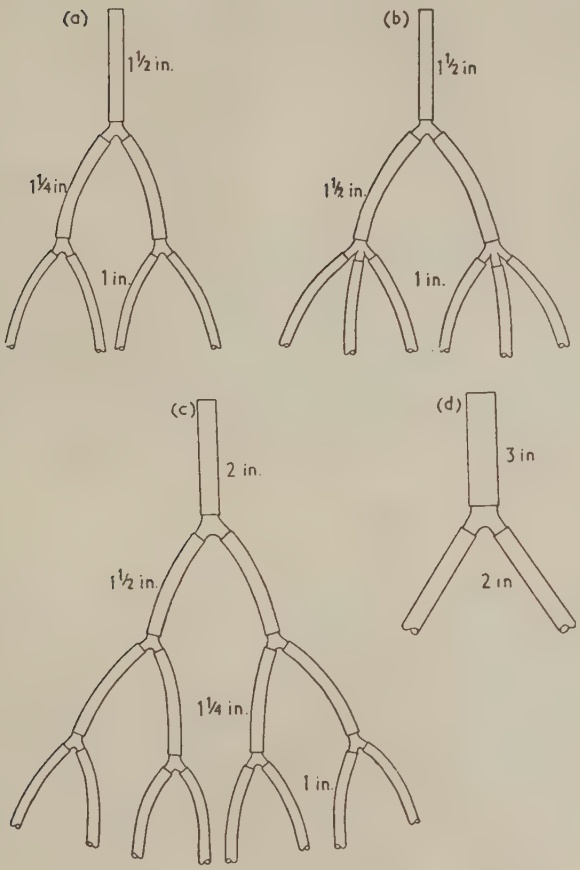


Fig. 4. Y-distribution for Hoddesdon pipes from 1½–3 in. mains.

Hoddesdons by hexagon unions or, for preference, quick-coupling joints (see Fig. 5). It is particularly important to ensure that all the pipes receive equal quantities of steam and for this reason the flexible hoses should be of equal length and other restrictions to steam flow, such as bends, should be equal. Similar considerations relate to the distribution of steam to spiked pipes as with Hoddesdon equipment.

To allow for continuity of work, all the equipment should be duplicated to permit of digging in whilst steaming is in progress — therefore another header, each branch with its separate valve, would be needed on the end of the steam main.

Heat Loss and Condensate

The heat lost from a steam main has two effects. Firstly, it is a loss of heat representing up to about 10 per cent of the heat delivered to the soil

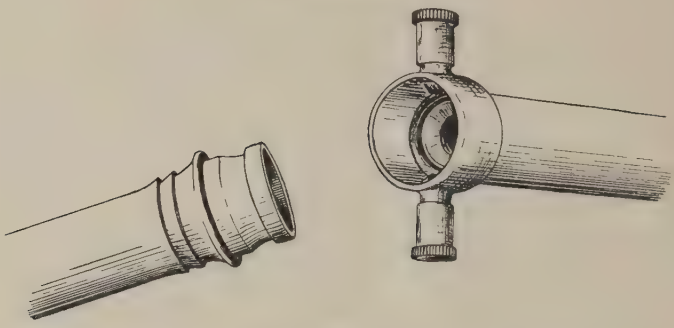


Fig. 5. Quick coupling for steam main.

and secondly, the resulting condensed water can play havoc with the efficiency of the sterilizing process if it is not drained off at the end of the main.

It is worth while to lag the mains in a cheap and simple manner in order to reduce the heat loss and condensation, but the latter must be dealt with by removing it at the end of the main or at the header. In the open, lagged pipes should be protected from rain or snow, as wet lagging is worse than useless.

The best method of draining condensate is to use a thermostatic steam trap such as is used on steam heating systems. This trap automatically passes water but not steam and the water should be led on to the soil already steamed or outside the glasshouse, so that the unsteamed soil does not become wet in patches.

To ensure effective drainage of condensate, the trap should be connected by about a foot of small bore pipe to a vessel or short length of large pipe, into which the water can settle. It is an advantage if the steam leaves this vessel through a short vertical pipe. In one design of steam trap the rotation of the steam flow also induces separation by centrifugal action: if the unit is properly designed, this is a very efficient method of separating water from steam.

Pressure Losses during Transmission

It has already been stated that the pressure of the steam in the boiler is entirely used up in delivering the steam to the soil. This loss of pressure is due to all the components through which the steam passes, which are the steam main, the distributor and the steam injection pipes. The final pressure drop always occurs at the holes through which the steam issues into the soil. In addition, other pressure drops may occur due to steam cocks, and a pressure reducing-valve if in use.

Examples of the pressure drop in steam mains are given in Fig. 6 for a boiler producing 1,500 lb of steam an hour. If the boiler pressure is 100 p.s.i., the whole of the pressure would be lost in a 1 ¼ in. main 300 ft long (curve A), whereas a 1 ½ in. main of the same length would lose only 26 p.s.i. (curve B). Thus the improvement to be gained by changing to the next larger sized main is quite considerable and an existing 1 ¼ in. main can be improved appreciably by replacing only the last 150 ft with 1 ½ in. pipe (curve C).

P.V.C. sheeting cover during steaming. Note also welded Y-pieces and quick couplings to Hoddesdon pipes.

P.V.C. sheeting cover showing the ballooning that indicates end of cook. Note also holding chain and the soil thermometer.

PLATE I

Forced draught fan and motor: a simple home-made arrangement for reducing boiler smoke.

Photo: National Institute of Agricultural Engineering

A portable sterilizing bin with steam grid in position.

Plough-type grid for mechanized steam sterilization.

PLATE III

Plough-type grid in operation.

PLATE IV

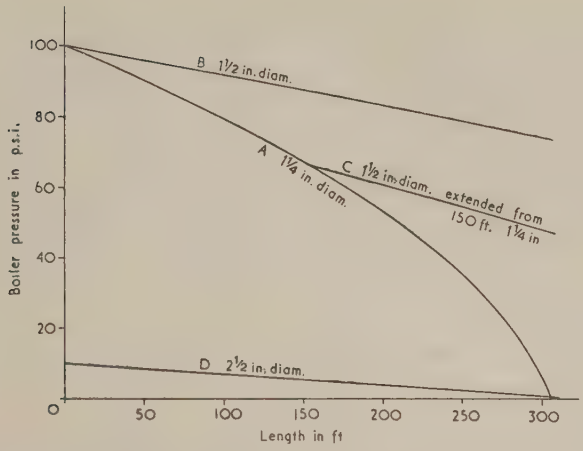


Fig. 6. Pressure drop in steam mains. Boiler pressure 100 p.s.i., flow 1,500 lb/hr

If the boiler works at a low pressure of only 10 p.s.i., with the same steam output of 1,500 lb/hr, a larger main would, of course, be required. In fact a 2½ in. main (curve D) would use all the pressure in a length of 300 ft, and any smaller size would not transmit the full boiler output. Thus, the comparison of curves A and D shows that the low-pressure boiler needs a main of twice the diameter and neither of these mains would be suitable for distances greater than about 250 ft.

It is difficult to lay down simple rules for main sizes, and use of the formula in Appendix IV will give the best answer in any particular case, but for high-pressure boilers, 1¼ in. mains are often suitable for boilers producing up to about 1,200 lb/hr and 1½ in. should be used for larger boilers. Steel pipes having either flanged or screwed joints are usually employed for high-pressure steam (see also Appendix I, Table 3).

For low-pressure boilers a wider choice of sizes and materials is possible, but 2 in. and 2½ in. are the most useful sizes. The material may be either steel or light alloy and several methods of jointing can be used. There are several types of aluminium irrigation pipe which have steam-tight quick-coupling joints, the light alloy fire-hose coupling can be butt-welded to aluminium pipe to make a very good main and, simplest of all, plain-ended aluminium pipe may be jointed by series of short sleeves of rubber hose secured with pipe clips.

Control of Pressure Drop

As the work of steaming proceeds down the glasshouse, the main is shortened and its pressure drop is reduced. The effect of this can be dealt with in several ways. The simplest method to describe is the one in which the boiler pressure is allowed to fall to any value decided by the pressure drop in the system. If, for a given length of main, the boiler pressure is initially higher than is needed, the steam flows at a greater rate than the steady boiler output, causing the boiler pressure to drop until the required value is reached. The output of the boiler is the same whether the boiler is running at a steady high pressure or at a steady low value.

This method works perfectly well for low-pressure boilers and although it can also be used for high-pressure boilers, some difficulties may arise. When the mains are shortened, pipe resistance decreases and the boiler pressure may fall to a value which is insufficient to actuate a steam-operated water injector. If this type of injector is being relied on, this pressure drop must be avoided by some means. Also the heat storage capacity of a high-pressure boiler is much higher than for a low-pressure one, as a result the pressure may not fall to the desired value sufficiently quickly and the cook may be done at too high a rate. These difficulties have led to the use of various means of controlling the pressure drop in the system as follows:

1. The steam valve on the boiler may be only partially opened in order to maintain boiler pressure when the main is short. This is not a good method of control.
2. The variation of pressure may be reduced by using a large main and increasing the pressure drop between the main and the soil in one of the three ways:
   (*a*) small holes, about $\frac{1}{16}$ in. instead of $\frac{1}{8}$ in., are used in the perforated pipes. This increases the pressure drop across the holes from about 2 p.s.i. to about 50 p.s.i. With an adequate size of main, this method is effective, but it is not much used;
   (*b*) the pressure in the distributor or header is adjusted by means of a hand-operated valve with a pressure gauge close to it on the downstream side. The required pressure is found in a few trial cooks and then the valve is used to maintain this pressure;
   (*c*) The hand valve of (*b*) is replaced by an automatic pressure reducing valve, which is set to give the required downstream pressure.

Use of Reducing Valve

The reducing valve undoubtedly gives the best form of control with a high-pressure boiler and as a result the cooks are all of the same duration regardless of the length of main, provided no changes occur in the condition of the soil. The disadvantages of a reducing valve are mainly the cost and the fact that an additional piece of equipment must be moved down the glasshouse. Reducing valves are not necessary on all high-pressure systems, but they are useful in many cases and their merits should be considered in each particular case.

A reducing valve controls the flow of steam in such a way that the pressure on the outlet side remains constant at a value depending on the adjustment. It therefore makes an automatic correction for variation in boiler pressure and varying length of steam mains. The opening of the valve is usually controlled by a spring-loaded diaphragm or piston. The spring can be adjusted by hand to vary the downstream pressure at will. If the number and size of holes in the buried pipes of any set of steaming equipment is known, it is possible to calculate the pressure required in the pipes, grids, etc., to give the correct rate of injection. As an example, with 7 ft Hoddesdon pipes spaced at 18 in., each with 34 $\frac{1}{8}$ in. holes, the pressure required in the pipes themselves is 2 p.s.i. A somewhat higher pressure would be required at the reducing valve.

The method of installing a reducing valve is shown diagrammatically in

Fig. 7. The unit consists of a strainer A, which prevents the entry of grit or scale. Any water in the steam is removed from the double elbow B through the steam trap C. An efficient steam trap is essential to prevent water being carried forward into the soil, and to get the maximum drying effect when the steam expands. The reducing valve D controls the flow of steam and maintains a constant pressure on the low pressure side; this pressure can be checked on the pressure gauge E. After being expanded through the valve, the steam passes to the breaching pieces or headers, and thence to the injection equipment. The reducing valve must be capable of passing steam at the required rate, depending on the area of soil steamed at one time (1,000 lb/hr for 54–60 sq. ft of soil).

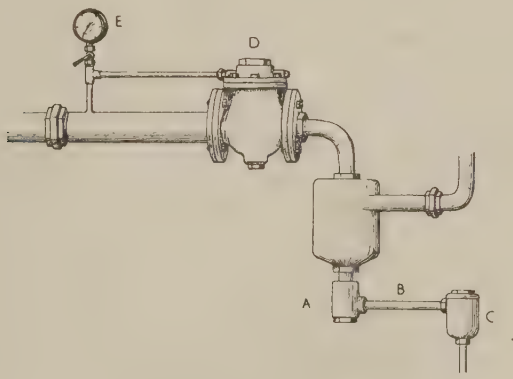


Fig. 7. Reducing valve assembly

The size of reducing valve required depends on steam flow, diameter and length of main, boiler working pressure and also on the make of valve. A 1½ in. valve is usually satisfactory for a 1,500 lb/hr boiler, but it is best to get advice from the manufacturers or the National Agricultural Advisory Service.

The reading required on the pressure gauge can be found by timing the steaming process and adjusting the valve until the process takes 1½ min for every 1 in. depth of loose soil. So long as the equipment between the reducing valve and the soil remains standard, this reading set on the gauge will always give the correct rate of injection. For ease in moving the assembly, it can be mounted on stands or on a small tubular skid.

When a reducing valve is used, it is particularly important to instal connections and flexible hose of sufficiently large diameter between the valve and the distributor, since steam pressure is comparatively low after the valve.

Steaming Operations with Hoddesdon Pipes

As the Hoddesdon pipe is the most effective and generally used equipment for soil steaming, the technique of operation in various circumstances is described more fully below.

Operation in 18 ft House

To return to the example given on page 16, the method of operation, using six Hoddesdon pipes set 15 in. deep and 18 in apart in a house 18 ft wide would be as follows (see Matching Plot Size to Boiler Output, page 8). A trench is dug along one side of the house 15 in. deep and 18 in. wide, and the soil from it is wheeled to the other side of the house for filling up the final trench. If, however, the house is one of a block, to save labour the soil from the first trench may be scattered in the first house, and the final trench filled up by taking a little soil from the surface nearby. Next, at the far end of the house, the bottom of the trench is broken up thoroughly to the depth of a fork and a single pipe is placed in it as close as possible to the wall foundations. The soil is then dug out from the ground alongside to cover the pipe and to open a second trench. In this way 7 ft of the first trench is filled and another trench 7 ft long, 15 in. deep and 18 in. wide is opened at the side of it. The bottom is forked up and the second pipe laid in position 18 in. away from the first. This is covered in like manner to the first, leaving a third trench to receive the third pipe and so on.

Since six pipes are to be steamed at one time, this work continues until seven pipes are laid in position. The surface of the soil should then be levelled, if this has not already been done, and the plastic cover put in position (see page 7). The first six pipes are then connected to the distributor and the steam is turned on. It will be noted that the seventh pipe is not connected up with the others, but it should always be placed in position, since it ensures that the sixth one is properly covered with soil. While the first six pipes are in use, the remainder of the second six are placed in position ready for steaming after the first plot has been sterilized.

As soon as the bulk of the soil has reached sterilizing temperature, as indicated by the lifting of the plastic cover, the steam is turned off at the end of the main. The second plot, which by this time is ready to be steamed, is covered with a second sheet, its six pipes are connected to the steam supply by transferring the flexible hoses from the pipes in the first plot and steam is turned on. Heat-proof gloves or cloths are useful to protect the hands when disconnecting the quick couplings.

While the second plot is being steamed, the third plot is prepared and the pipes and covering from the first plot pulled forward into it. In this operation the first pipe is withdrawn from the steamed plot into the open trench against the glasshouse wall, leaving about 6 in. still projecting into the first plot to ensure a slight overlap of the plots. This pipe is then covered with soil as before by opening a trench alongside for the second pipe, which is then withdrawn and covered in from the third trench. In this way the six pipes are moved to their new position, care being taken to thoroughly loosen the bottom of all the trenches before covering with soil. When the second plot is hot the hoses are transferred to the new third plot, and the seventh pipe is withdrawn and covered from the fourth plot alongside, before pulling forward the sheet from the first to the third plot. Steam is then supplied to the third plot while the fourth plot is being prepared.

As the work proceeds down the house, sections are successively removed from the steam main as necessary, each section usually being about 15–20 ft long. In this manner, the soil, two plots wide, is eventually steamed throughout the whole length of the house.

Operation in 30 ft House

Taking as another example a house 30 ft wide which is being steamed with a 2,000 lb boiler — the minimum area to be steamed at one time is about 112–120 sq. ft. For an even number of pipes to be used, a convenient spacing would be 15 in., as at this spacing twelve pipes each 8 ft long will steam 120 sq. ft. Twenty-four pipes would be needed to steam the full width of the house, and this could be done in two groups of six pipes at a time, using distributors of the branched-pipe type illustrated in Fig. 4 (*b*). The procedure would be similar to that in the preceding example, except that twice the number of pipes would be in use at a time. In this example using standard 7 ft pipes it would be difficult to get a good fit of plots across the house and at the same time make them large enough to match the boiler output.

Operation in Block of Houses

In a block of houses, if there are no dividing partitions, to avoid unnecessary handling of the main as work proceeds, the dismantled sections can be moved into the next but one house. When house 1 is completed the Hoddesdon pipes are placed in position at the corresponding end of house 2, the distributors are connected to the shortened main lying in house 3 by steam hose, and work proceeds in house 2 in the reverse direction. When house 2 is finished the pipes are moved to house 3, where the main is already laid, and the whole process repeated, i.e., odd numbered houses are steamed by shortening the main, and even numbers by lengthening it. The soil for covering the last trench in the first house is taken from the first trench in the second house, and so on.

To avoid creating a trough in the last house steamed by the Hoddesdon pipe method, it may be necessary to work in the opposite direction in successive operations, unless the soil from the first trench is used for filling in the last trench. The main should never be laid over soil already steamed.

Some growers prefer to work in one direction only, i.e., they will start in house 1, furthest from the boiler, and work towards the boiler. When house 1 is completed the pipes are all carried to the furthest end of house 2, the main is relaid and the process repeated in the same direction, in each house.

Strip Steaming

Where there is no serious pest or disease problem, strip-steaming of the beds is sometimes practised, and the intervening paths are left untouched as a method of reducing steaming costs. It should be pointed out, however, that, with this method, there is an increased risk of recontamination of the steamed beds from the unsterilized paths.

STERILIZING SMALL QUANTITIES OF SOIL

Many devices have been invented by nurserymen and others for sterilizing soil in quantities varying from ½ ton to 3 tons or more, but the methods most commonly used at the present time are soil heating by medium- and low-pressure steam and, to a small extent, by electricity.

In the past, soil baking by fire heat was sometimes employed, but the method cannot be recommended. However carefully it is done, it is impossible

Hot-gas Rotating-drum Sterilizer

In this method soil is fed by hand into an inclined rotating-drum. Hot gases from an oil-fired burner are passed through soil as it is tipped over and over on its way through the drum to the delivery end where it is discharged in a heap. The rate of throughput has to be adjusted in accordance with the moisture content, so that the soil reaches sterilization temperature but is not overheated. Because of this it is important that the rate of throughput should be kept constant after the correct rate has been found.

Moisture is necessary in the soil to prevent burning; the soil should, therefore, be slightly wetter than for steaming. Excessive moisture should be avoided, however, as it leads to the formation of balls of soil as well as increasing the heat requirement.

With this method there is little delay between starting the unit and the production of sterilized soil. The unit is particularly suitable for frequent production of batches of potting soil in amounts greater than could be conveniently produced by electrical sterilizers and where steam is not readily available.

Sterilization by Electricity

Electricity may be used for sterilizing soil in quantities from as little as 1 cu. ft up to 1 cu. yd per charge, and is a convenient method where only small quantities are to be treated. Two types of apparatus in use are soil-resistance and immersion heater sterilizers.

The smaller electric sterilizers are useful to the amateur gardener as they can be worked from a domestic heating point, the average maximum demand being 10 amp. The maximum demand of the larger models varies between 30 and 60 amp and can only be used satisfactorily on 400 volt three-phase circuits. Electric sterilizers can only be used for heating soil. Pots and boxes would have to be sterilized by one of the other methods.

Soil Resistance Sterilizer

The soil is loaded between two metal plates, between which the current is passed. The soil acts as a resistance and heats up. As the temperature rises the current increases, but at 212°F steam is evolved, the soil near the plates begins to dry out, increasing the electrical resistance, and the current is cut off automatically.

To give uniform heating and effective sterilization, the soil should be as wet as possible, without impairing its physical condition, and well firmed in the sterilizer. Dry loose soil heats unevenly and may not reach 212°F before the current cuts off owing to the high soil resistance. At temperatures below 212°F heating may not be uniform and there may be cold spots with imperfect sterilization.

A sterilizer of the soil resistance type should not be home-made, as it has a very high peak load and unless it is well built there is a serious risk of electric shock. It should be fitted by an electrical engineer and should have an interlocking switch to prevent the current from being switched on until the container is closed.

Immersion Heater Sterilizer

This type consists of a series of heating elements contained in tubes or plates fixed into a soil container. The passage of current heats the elements

which in turn heat the soil. From an electrical point of view this type is favoured, as it has a constant low load factor and there is less risk of shock than with the soil resistance type. The principle used is similar to that in a soil baker. It is possible to overheat the soil, particularly near the tubes or plates, though in the latest designs this is reduced to a minimum, provided the soil is sufficiently moist.

Sterilization by Chemicals

MANY chemicals have a partial sterilizing effect when applied to soil, and to a limited extent provide an alternative to steam. Experience has shown, however, that, of the substances commercially available in Britain, formaldehyde is the most satisfactory for the destruction of fungi that cause diseases such as foot rot, *Verticillium* wilt and root rot. Promising results in the control of disease have recently been obtained under commercial conditions with chloropicrin injected into the soil. Other substances, such as cresylic acid, proprietary phenolic soil disinfectants, carbon disulphide and dichloropropane-dichloropropylene (DD) mixture may be employed where the primary object is the destruction of insects or eelworms. Cresylic acid and other phenolic soil disinfectants are of value for the destruction of woodlice and millepedes. Carbon disulphide is used for the control of symphylids and may be employed to control wireworms when root crops susceptible to tainting by BHC insecticides are to be grown. Dichloropropane-dichloropropylene (DD) mixture is highly effective in controlling the root knot eelworm (*Heterodera marioni*) but sterilization by steaming remains the most satisfactory treatment against the potato root eelworm (*H. rostochiensis*).

TIME OF APPLICATION

The time of application of the chemical must be regulated in accordance with the cropping and the period required for the disappearance of the chemical from the soil. Formaldehyde is usually applied soon after the soil has been dug, following the removal of a crop in the late autumn.

Provided the requisite periods are allowed between treatment and planting (see sections dealing with specific chemicals), most of them can be applied at any time of the year. Carbon disulphide, however, is best used against symphylids early in the year when the soil has been warmed before planting.

SOIL PREPARATION

Most chemicals may be either added to the surface of the soil as each trench is completed during digging operations, or watered over the soil after the whole house has been dug, whichever is the more convenient. In either case all pathways must be dug and saturated with the material which must also be applied to all dollies, bases of stanchions, brick walls, etc. As chemicals are only effective when they reach every particle of infected soil, the best effect can only be obtained if they can penetrate to whatever depth the infection extends. About three-quarters of the roots of the tomato are

in the top 12 in. of soil under average glasshouse conditions, but some roots penetrate to a depth of several feet.

The depth of soil wetted by a given quantity of chemical depends on the texture and state of dryness of the soil, and the following table gives a rough guide to the capacity of different soils for holding water. For example, twice as much water is needed to wet a clay loam to a given depth as is needed for a sandy loam.

TABLE 2

Water-holding Capacity of Soils

Depth	*Gallons per square yard at field capacity*			
	8 in.	*10 in.*	*12 in.*	*15 in.*
Sandy loam	5	6	7	9
Loams and silt loams	8	10	12	15
Clay loams and silty clay loams	10	12	15	18

In practice, chemical sterilization seldom exceeds a depth of 10 in. at one application, and when deeper penetration is necessary, it is usual to apply the solution separately to the second spit during digging. All parts of the glasshouse which might be a source of reinfection should be sterilized. The soil should be brought to a seedbed condition with no large clods which the chemical would be unable to penetrate. The surface should be left as level as possible to prevent puddles forming when the soil is treated. Deep rotary cultivation is often a useful method of preparation. The moisture content of the soil before treatment is important: it should not be in a very dry state, otherwise the chemical does not penetrate easily. A moisture content slightly below that for potting composts is suitable.

If the surface is dry, a light watering should be given three days before treatment. If deep sterilization is necessary the soil must be double dug and the chemicals watered over the surface of the second as well as the top spit. When digging over the house, all concrete dollies supporting the roof, the walls of the houses and stays supporting hot-water pipes must be exposed and watered with the chemical sterilizer. Chemical sterilizers are rarely completely satisfactory in very heavy soils, and they are ineffective against deep-seated soil infection. To prevent recontamination of treated soil, precautions similar to those with steamed soil should be taken (see page 4).

Where a following crop is to be planted after chemical treatment, it is advisable to use test plants to indicate whether conditions are safe before planting up the treated house. Lettuce seedlings are frequently used for this purpose and if these are unharmed, it can be assumed that the amount of DD fumes remaining in the soil has fallen below a level dangerous to plants.

METHOD OF APPLICATION

When applying the sterilizing fluid, it can be mixed with the necessary amount of water in a barrel or tank, lifted above the ground on a lorry outside the house or on trestles within the house. If a tap is placed near the bottom, the liquid can be run out easily through a hose with a sprinkler on the end, or it can be siphoned out. Spray lines with suitable nozzles are sometimes used to give even distribution.

On many nurseries it is most convenient to mix formaldehyde with the water in the nursery water tank and apply it through hoses attached to the stand-pipes or through spray lines. It is essential to flush out thoroughly the tank, water mains, hoses and spray lines before watering plants. Thorough mixing in the tank is essential and is best accomplished by adding the formaldehyde when the tank is about one-quarter full.

The easiest way to apply chemicals is to measure the surface to be treated and divide it into widths across the house. By measuring the rate of flow of the solution from the hose attached to the tank containing the chemical the time taken to water each 10 sq. yd can be calculated and the correct amount of sterilizer fluid can be watered on the soil.

Automatic dilutors which work on the principle of the Venturi tube are widely used for applying chemical sterilizers. For efficient working, the water must be at comparatively high pressure. At the low pressure provided by the average nursery water tank, the rate of dilution is not constant but fluctuates with variations in the water pressure. More efficient dilutors for low-pressure water systems are available which rely either on piston action, or on the principle of a moving diaphragm, but they cost much more than the Venturi type.

Special soil-injecting equipment is needed for the injection of chemicals. Soil injectors are of various types, but adjustable ones that can be set to deliver given quantities per acre at the required spacings are obtainable and to be preferred. It is necessary, however, to check the adjustment from time to time during working use. The injection holes in the soil can be effectively sealed with the heel as injection proceeds. Soil injection is heavy work, and some injectors are lighter in weight and easier to manipulate than others.

Materials Used

Formaldehyde

Formaldehyde has been used on a large scale as a soil sterilizer and is the best one available for controlling soil-borne diseases. The commercial product is sold at a concentration of 37·5–40·5 per cent, of which 1 gal is mixed with 49 gal of water. For general use on glasshouse soils, that quantity (50 gal) is applied to 10 sq. yd of soil, and at this rate, penetration may extend to about 8–10 in. in a light soil, and 5–7 in. in a heavy soil, provided it is fairly moist before treatment. Penetration into heavy soils is often unsatisfactory.

On some types of soil, particularly those that can be worked to a depth of 2 ft, better results have been obtained by applying formaldehyde to the top 16–20 in., using the following method: prepare the borders for double digging by opening a trench 3 ft wide along one end of the house, and remove the soil to the end of the house where the digging operation will finish. Then turn over the bottom spit of soil and soak thoroughly with formaldehyde solution. Immediately afterwards, cover the soaked soil with the top spit from the next 3 ft of soil parallel to the open trench and thoroughly soak the top layer, repeating the two operations in this manner until the border is completed. This method of applying formaldehyde will take 8–10 gal solution per sq. yd, and with light soils ensures thorough treatment to a depth of 16–20 in.

Plants should not be brought into the houses until all trace of vapour has disappeared from the air. In winter and early spring this takes about

six weeks in unheated houses, in which the top spit only has been treated, but less time is required in late spring and summer. The dispersal of the vapour depends on the soil temperature, the type of soil and the depth of treatment. If the formaldehyde has penetrated deeply in a heavy soil and prolonged cold weather prevails, much more than six weeks may be necessary for the vapour to disperse.

Formaldehyde is sometimes used by growers of mustard and cress specifically as a preventive treatment for damping-off diseases. A 1 per cent solution is applied at 1 gal to 10 sq. yd as the final preparation of the bed before sowing. There should then be a delay of 24 hours before sowing to allow clearance of fumes.

Formaldehyde for soil sterilization is unstable and slowly changes (polymerizes) with the formation of an insoluble white sediment. Polymerization is hastened by low temperatures, so formaldehyde should be kept in a warm place and never exposed to frost. To delay polymerization, a stabilizing agent is normally added, but this does not entirely prevent the trouble; in time a thick milky precipitate forms, which does not volatilize, and reduces the concentration of the liquid, so that less water is needed to make a 2 per cent solution. The insoluble residue should not be disturbed by stirring in an attempt to dissolve it, and it should not be applied to soil, as it is toxic to plants and in some soils it may persist for many weeks or months.

Chloropicrin

Chloropicrin, more commonly known as tear gas, is used to a limited extent for soil sterilization. It appears to be at least as effective as formaldehyde in controlling soil-borne fungi and is effective in controlling root knot eelworm. It is injected into the soil before planting, the period between injection and planting depending on the weather conditions and soil temperature. As a rule, the interval should be not less than eight weeks, but planting of tomatoes has been carried out in midsummer within two weeks without any ill effects. The injections are usually made at 12 in. spacings to a depth of 6 in., the injector being set to deliver 3·5 c.c. chloropicrin at each stroke. Good results have been obtained with a dosage of 300 lb per acre (34 gal); increased dosages are more effective but cost is the limiting factor. The soil should be moderately dry, and after the treatment a light watering (about 1 gal per sq. yd) prevents escape of the fumes into the air. After not less than seven days, preferably slightly longer, release of the fumes can be quickened by digging over or rototilling the treated soil, and turning on the pipe heat. A respirator has to be worn by the operator. Chloropicrin is also effective in controlling weed growth. The vapour is very toxic to growing plants and cases are known where a glass partition has not been sufficient to protect a crop of young lettuce growing in an adjoining glasshouse.

Phenolic Fluids

For many years cresylic acid was widely employed for the treatment of glasshouse soils, but is now little used. The usual dilution is 1 gal 97–99 per cent cresylic acid to 40 gal of water, and this is applied at the rate of 40 gal to 10 sq. yd. Proprietary phenolic sterilization fluids containing higher boiling phenols are obtainable. As these phenols are much less soluble than cresylic acid, they are formulated to yield emulsions on dilution with water.

In practice, the results obtained by the use of such sterilizing fluids for the control of fungus diseases and for the restoration of soil fertility have been less satisfactory than those given by formaldehyde. Their insecticidal properties, however, are more pronounced than those of formaldehyde; consequently they are of value against pests such as woodlice and millepedes, but satisfactory control of eelworms is very rarely obtained.

The period which must be allowed between treatment of the soil and planting depends on the composition of the fluid, and the user must be guided by the makers' instructions. As a general rule, at least six weeks are necessary.

Carbon Disulphide

Carbon disulphide may be used to control symphylids and wireworms. It does not mix with water but it may be injected into the soil or watered on in an emulsified form. The vapour has an unpleasant odour, is very inflammable and also injurious if inhaled. Consequently, the maximum amount of ventilation should be given, and smoking or the use of naked lights forbidden during treatment.

In the injection process, a measured quantity of neat carbon disulphide is forced into the soil at a predetermined depth. The depth, spacing and quantity of carbon disulphide injected depend on the nature of the soil; the vapour disperses over a greater area in a dry, open soil than in a heavy or wet soil. In very light, open soils, the injections may be 18 in. apart in either direction, and $\frac{2}{3}$ fluid oz of carbon disulphide injected at each insertion. In medium loams, $\frac{1}{2}$ fluid oz should be injected at intervals of 15 in. in each direction, and in heavy soils $\frac{1}{3}$ fluid oz inserted at intervals of 9 in. is necessary. The quantities of carbon disulphide required are $1\frac{1}{2}$ pints per 100 sq. ft or 82 gal per acre for very light, open soils; $1\frac{3}{4}$ pints per 100 sq. ft or 100 gal per acre for medium loams; and 3 pints per 100 sq.ft or 160 gal per acre for heavy soils. The depth at which the carbon disulphide should be injected is difficult to decide, and failures to control wireworms and symphylids are probably due to the insects being deeper than the range of the vapour.

Where a lettuce crop has been grown, the wireworms are usually near the surface, and so injections at a depth of 6 in. often appear satisfactory. Where the soil in tomato houses is treated immediately the old crop has been removed, or as late as possible before planting, injections at a depth of 10 in. are suggested.

Proprietary emulsions of carbon disulphide are available which are sufficiently stable on dilution for them to be mixed in a tank and watered on to the soil through hoses. Good results in the control of wireworms in tomato borders have been obtained with a 50 per cent emulsion diluted to 1 in 300 and applied at 10 gal per sq. yd. Three pints of the concentrated emulsion are required for each 100 sq. ft or 162 gal per acre. Where the soil is too wet to apply 10 gal per sq. yd, it may be possible to employ a smaller quantity of a stronger mixture.

Good control of symphylids has been obtained by treatment of the soil with a 50 per cent emulsion diluted to 1 in 200 and applied at 8 gal per sq. yd, or 190 gal concentrate per acre.

The fungicidal value of carbon disulphide is much inferior to that of formaldehyde and where soil sterilization is required in addition to the

destruction of symphylids or wireworms, it is possible to apply a mixture of formaldehyde and a proprietary carbon disulphide emulsion in one operation.

DD

DD (*dichloropropane-dichloropropylene*) mixture is the trade name of a by-product in the manufacture of alkyl plastics, widely used as a soil fumigant for the control of eelworms. DD is a volatile inflammable liquid, which is normally injected into the soil to a depth of 8 in. at 15 in. square spacing at a rate of 400 lb per acre. The material is used mainly against the two species of eelworms which attack the roots of tomatoes under glass. It has proved very useful in many cases where soil sterilization by steam would have been impracticable. This applies particularly to small or awkward houses where the hire of steam sterilizing equipment would be uneconomic.

It is in fact a better control for root knot eelworm than steam, but is rather less effective against potato root eelworm. In most cases, however, unless infestation with potato root eelworm is high, DD injection at the rate of 400 lb per acre will ensure a satisfactory tomato crop. Some growers have now used this material for 6–8 years in succession and continue to get good crops, although the cyst content of the soil often remains at a fairly high level.

DD may also prove useful where steam sterilization is practised, as a means of lengthening the time before steaming need be repeated. In eelworm infested houses, steaming must be carried out annually or at most every second year, but this period can be lengthened to once in four or more years if DD is used in the intervening years. Furthermore, improved crops often follow its use even when eelworm infestation is absent. It is not, however, a fungicide, and does not control root-rotting organisms.

The optimum soil temperature for efficient fumigation is 60°F so that injection immediately after the tomato plants are lifted while the soil is still relatively warm is advantageous and fumigation is completed within a few days. In cold conditions a period of a month is desirable before reworking the soil to disperse the fumes. Instances have been reported of the tainting of tomatoes when DD has been used regularly on heavy soil.

Metham-sodium

A chemical soil sterilizer containing metham-sodium (sodium-methyldithiocarbamate) has been successfully used in the U.S.A. under field as opposed to glasshouse conditions for several years and products containing this chemical are now available in this country. The chemical appears to give better results than formaldehyde for the control of certain root rots of tomato (e.g., *Colletotrichum* root rot and the brown root rot or "corky" disease) and also gives a marked measure of control of root knot and potato root eelworm. It is also effective in reducing weed growth. Proprietary products consist of concentrated metham-sodium solutions which are either diluted and applied to the soil through a hose or watering can or injected into the soil.

Volatile decomposition products from metham-sodium application are very toxic to plants and serious losses have been reported from vapour spreading into other houses through ventilators, ducts, doors or partitions. It should also be emphasized that the exact conditions for the safe usage of

this chemical are as yet incompletely understood. Consequently, cases of serious damage to crops following soil treatment were encountered during the 1958 season.

The conditions necessary to obtain satisfactory results without any risks to the crop to be planted, and, in particular, the interval required between application and planting, cannot yet be stated but experience suggests that when metham-sodium is applied during the winter a period of several months is required. Much shorter periods are required when metham-sodium is applied to warm soil and when the soil is forked over several times to hasten the disappearance of the decomposition products. Highly organic soils are more likely to give trouble than those with a low organic content.

The vapour from diluted metham-sodium is very irritating to the eyes and nose, and glasshouses should be fully ventilated during its application and for a week or so afterwards. For personal comfort the wearing of a respirator is recommended. Rubber boots and gloves should be worn when handling the concentrate.

In the present state of knowledge, the advice given by the manufacturers on their labels is the best available and should be closely followed if the risks of damage to plants are to be minimized.

Treatment of Small Quantities

Where propagating soil cannot be steam-treated, chemical sterilization offers an alternative to other methods. A solution for the control of fungus diseases in the soil may be made by mixing 1 gal of 40 per cent formaldehyde with 49 gal of water. It is best to treat the soil in layers 6 in. deep, gradually building up the heap. Fifty gal of diluted formaldehyde will saturate about 1 cu. yd of very heavy soil or 2 cu. yd of sandy soil. For smaller quantities of soil the rate of application is 1 gal diluted formaldehyde solution per bushel of soil. The soil should be thoroughly saturated with the solution and covered with damp sacks for 48 hours; the heap should then be uncovered and turned to allow all traces of formaldehyde to disappear before use. A safe period is 4–6 weeks, but this may be shortened by placing the soil in a warm empty house or over hot-water pipes.

Soil Treatment after Sterilization

No matter what method of sterilization is used, it is costly in time, labour and materials and all this trouble and expense can be wasted by subsequent carelessness. It is essential that newly-sterilized soil should be protected from contamination by contact with unsterilized materials. Disease organisms from contaminated soil or equipment multiply rapidly in freshly treated soil which may thus become seriously infected again.

Workers should not walk from unsterilized houses into sterilized ones. Keep the houses locked except when it is necessary to enter for forking, flooding or applying fertilizers, and at such times see that the workers' boots have been dipped in dilute formaldehyde or cresylic acid. Paths outside the houses may be sprayed with formaldehyde or cresylic acid to reduce the risk of reinfection. Forks, barrows, trowels, hoses, pots, boxes and

staging should be dipped or sprayed before taking into a clean house, or pots may be steamed where facilities exist.

All water used for flooding should be clean. Surface water and water from tanks in the houses should not be used unless there is no alternative supply.

After Steaming

Border Soil. As the soil is allowed to get dry in preparation for steaming, it is necessary to build up the water reserve again by flooding before cropping. The amount of water needed is about 6–9 in. in all; this is given in three equal applications and the soil forked between applications.

As some plant nutrients locked up in the soil may be released as a result of steaming, dressings of stable manure and nitrogenous fertilizers should be cut down or omitted, and potash in the base dressing increased for tomatoes.* If soil conditions are very rich after steaming, there is much to be said for working in 3–4 tons per acre of chopped straw to reduce the excess nitrogen.

Hard and fast rules cannot, however, be laid down concerning manuring, and some judgment is needed, both in dealing with land steamed for the first time and with land steamed regularly. Some stable manure may well be needed on poor land, and on land of reduced fertility where steaming is a regular routine. The manure should be supplemented by a little nitrogen in the base dressing, particularly with varieties that need rich conditions. Where manure has to be given, it should be applied before steaming and thus sterilized with the soil. It remains generally true that less nitrogen is needed on steamed than on unsteamed soils, but all dressings should be adjusted to the growth condition and needs of the plants. Steamed soil can be planted up quite safely as soon as its temperature has dropped to a suitable level.

Tomatoes always make rapid growth in steamed soil. It is best to set out sturdy plants with the first truss showing. Such plants tend to set fruit early after planting and the swelling of this fruit helps to retard vegetative growth.

Soil for Composts. Freshly-steamed loam can be incorporated with the compost ingredients as soon as it has cooled down, and the compost can be used immediately for potting, etc. If not needed at once, the loam should be spread in a shallow layer not more than 2 ft deep, preferably on a clean concrete floor in a weather-proof building, where it can be used at any time, provided re-contamination with pests and diseases does not occur (see also page 39, under Layout of Soil Shed). Under conditions of poor aeration as in a large heap of soil, chemical changes occur which result in the production of materials toxic to plants. Besides stacking in shallow heaps, the freshly-steamed soil should be allowed to cool as quickly as possible.

The increase in available nitrogenous compounds following steaming may have a harmful effect on seedlings. It is partly dependent on the nature of the soil, being greater as the content of decomposed organic matter increases, but mainly on the period of steaming, being greater the longer the temperature is maintained at 212°F. The production of ammonia in

* For fuller particulars of cultivation see Bulletin No. 77, *Tomatoes*. Price 4*s*. 6*d*. (4*s*. 11*d*. by post). Obtainable from H.M. Stationery Office (addresses on back cover) or through any bookseller.

such soils is also increased if they contain much lime. The build-up of ammonia, however, takes time and may reach a maximum about three weeks after steaming. Thus, there is a greater danger of injury, due to excess of ammonia, if seedlings are transferred to it 2–4 weeks after steaming than very soon after. Where a build-up of toxic chemicals is suspected, the soil can usually be much improved by one or two heavy waterings before seed sowing or transplanting. In general, steaming should be stopped as soon as the soil has been heated to 212°F.

Steamed soils which are deficient in phosphates have been found to cause more injury to seedlings than soils high in phosphate, and superphosphate should be added to the loam stack when it is being built.

After Chemical Treatment

Chemical vapours are poisonous to plants, which should not be brought into the houses until all trace of toxic material in the air or soil has disappeared. This takes about six weeks in winter and early spring, but possibly only 7–10 days in late spring or summer. Doubts about the safety of the soil for planting can be settled by setting out a few test plants and watching for damage.

Keep the house closed for a few days after applying the sterilizer. Then ventilate the houses and fork over the border to admit air freely to the soil. A few days later fork over again.

After about a fortnight a heavy flooding may be given, which will wash much of the residue of the chemical from the soil. As chemical treatment does not normally produce the same rise in fertility as steaming, the normal manurial practice of the nursery should be followed.

Frequency of Treatment

No hard and fast rules can be laid down for every nursery, and the programme for each must depend entirely on the prevailing conditions from year to year. Primarily, the frequency of sterilization is governed by the incidence of diseases and pests. Some of the most successful long-established tomato and cucumber nurseries are steamed every year, because if steaming is discontinued for one season yield drops substantially and consequently the difference in returns more than pays for the cost of annual steaming. Newer nurseries, which are freer from serious soil diseases and pests may maintain yields if steamed once in 2–3 years and chemically treated in the intervening years. Only careful observation and records, coupled with long experience can decide which in the long run is the best programme for a particular nursery.

Layout of Soil Shed

The layout of the loam stack, shredding floor, steaming bins, mixing floor, compost bins, etc., should involve the minimum of handling and transport and provide an easy flow of work along the sequence of operations, whether fixed or portable steaming bins are employed.

There should be sufficient mixing space and adequate storage accommodation with satisfactory isolation of clean material.

Storage accommodation is needed for the compost ingredients. Sand, peat and fertilizers are free from organisms likely to cause disease on glasshouse crops, at least whilst they remain in the condition in which they arrive on the holding. They are not needed until after the loam has been sterilized and should be stored close to the mixing floor.

The peat should be moistened before use. This may be done by breaking down the bale, sifting through a $\frac{3}{8}$ in. sieve and sprinkling with water; or by soaking in a trough and draining; or by adding water to the peat whilst still in the bale. The last method involves driving holes into the bale and adding water repeatedly over several days, or arranging for water to drip on to the bales for some days.

Whatever the source of the loam, it should be sterilized. It usually needs to be dried before steaming and is best stacked under cover somewhere close to the sterilizing bins. A simple open-sided shed is all that is needed. This should have a roof high enough to give comfortable working for stacking the loam and later cutting it down in readiness for steaming.

The plan in Fig. 9 shows a layout with a soil shed immediately adjoining the floor, where the loam can be broken down in readiness for steaming. From the floor the soil is moved to fixed steaming bins, two being needed to permit unloading and loading of one while steaming is in progress in the other. From the bins the loam is thrown to cool on the second floor. It may be mixed or stored as required. If necessary, seed or potting composts may be stored in bins until required, but should be used within six weeks of mixing. The shorter the storage period the less the risk of reinfection.

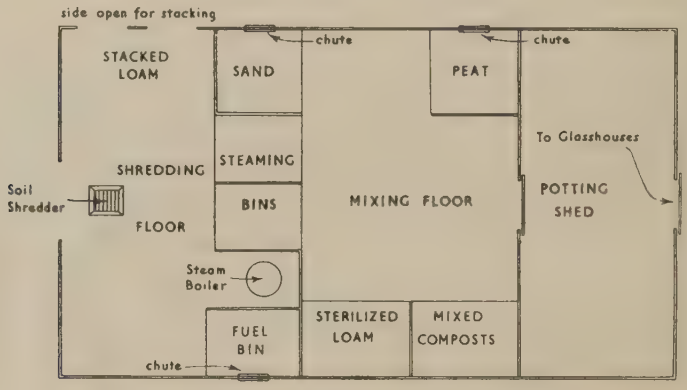


Fig. 9. Layout for soil shed with fixed sterilizing bins

It is an advantage if fixed sterilizer bins can be so sited and constructed as to discourage workers from passing between the two sections of the shed. It is also important to use separate sieves and shovels for the sterilized and unsterilized loams.

Where portable bins are used, a steam valve must be provided in an accessible place, so that a lorry, soil bin or pallet truck can be brought close up to the valve for steaming. The risk of reinfecting steamed soil can be reduced by having two pallet trucks and several portable bins. It is then

possible to use one truck for bringing the soil from the stack to the steaming point, and another separate truck for running on the clean floor only to pick up the steamed soil for use (Fig. 10).

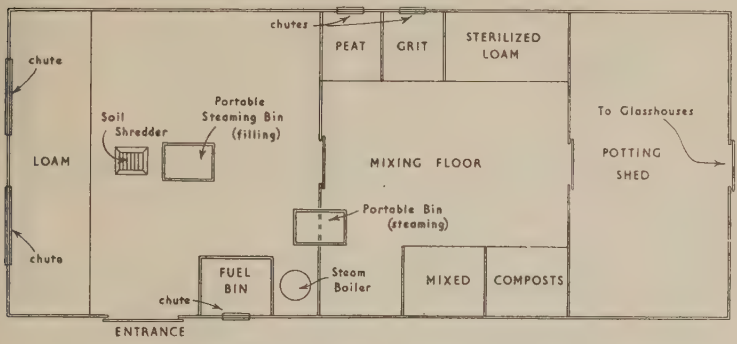


Fig. 10. Layout for soil shed with portable sterilizing bins

Whether existing buildings are adapted or new ones erected, every effort should be made to plan for full economy of labour and to develop the simplest order of sequence from stacking the new loam to mixing and using the composts.

The final preparation of compost is not strictly a part of this bulletin and for information on this the reader is referred to Advisory Leaflet No. 471: *Seed and Potting Composts** and the John Innes collected leaflets†

* Single copies free from Ministry of Agriculture (Publications), Soho Square, London, W.1.

† See footnote on page 29.

Appendix I

SUMMARY OF POINTS IN STEAM STERILIZING

(The encircled numbers in Figs. 11–13 refer to the paragraphs in the respective sections below.)

Boiler

1. *Smoke Control.* Ascertain your obligations under the Clean Air Act, 1956 (see page 12 for Ministry's free leaflet). Correct draught, stoking and suitable fuel help to reduce smoke.

2. *Draught.* Chimney of adequate height. Steam blowers in chimney are very wasteful, replace where possible with forced draught fan and sealed ash pit These not only help to improve draught but also make possible use of low-grade fuels, reduce smoke and make boiler more responsive.

3. *Good Lagging.* Reduces heat loss from the boiler shell. This loss can be as much as 5 per cent of the output.

4. *Fuels.* Many boilers can be fitted with automatic stokers or oil burners to increase burning efficiency. Smokeless fuels such as coke can be burned on most boilers by adjusting fire-bar spacing and draught when operating in built-up areas.

5. *Correct Stoking.* Means fuel economy. Keep a bright fire. Emit the minimum of smoke. Read the Stokers' Manual (see page 14).

6. *Output.* Check the rated output by measuring the feedwater input to maintain a constant water level over a period at full load.

7. *Feedwater Treatment.* Use correct water treatment to minimize scale formation and prevent corrosion.

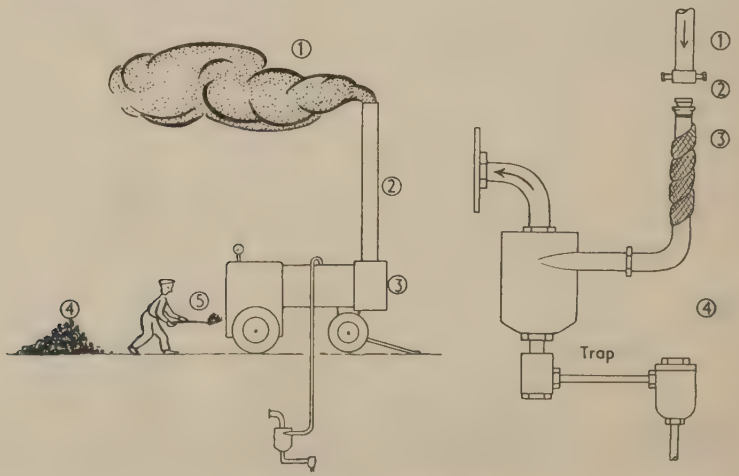


Fig. 11. Boiler, main and trap

Main

1. *Correct Size.* Mains must be large enough for the load required. The carrying capacity under glasshouse nursery conditions for a main 200 ft long is roughly as follows:

Table 3

Pipe diameter (nominal)	*Capacity of 200 ft main (lb/hr steam)*		
	Boiler pressure (lb/sq. in.)		
	85	*15*	*10*
in.	*lb/hr*	*lb/hr*	*lb/hr*
1	800	—	—
1¼	1,600	350	—
1½	2,400	550	350
2	4,300	1,000	700
2½	—	2,000	1,300
3	—	3,100	2,000

2. *Types.* Steel for high pressure. Light alloy for low pressure. Some irrigation mains suitable. Use quick coupling joints where possible.

3. *Lagging.* Heat loss from an unlagged main (200 ft long, 1,500 lb/hr steam).

Type of Main		*Percentage loss of heat throughput*
1¼ in. steel	(high pressure)	6¼
2½ in. steel	(low pressure)	5
2½ in. light alloy	(,, ,,)	2½

Loss can be reduced to ⅛ by lagging. Lagging material should stand rough handling; felt strip is one of the most satisfactory materials, but should be protected from rain, as wet lagging is useless.

4. *Layout.* Avoid sharp bends and keep number of bends to a minimum.

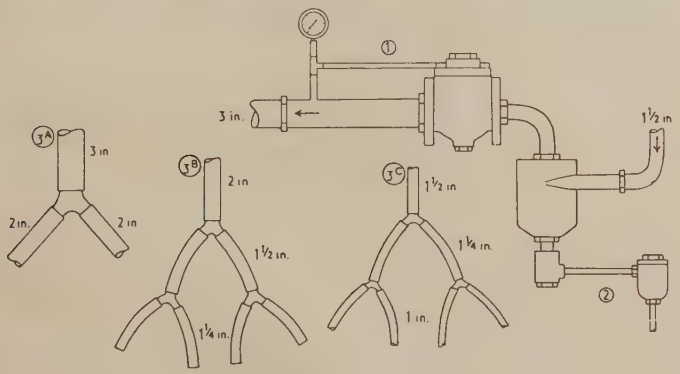


Fig. 12. Reducing valve and distributors

Distribution of Steam

1. *Reducing Valve.* Is a good method of controlling rate of steam flow and hence rate of injection of steam into soil (see overpage). It will compensate

within wide limits for changes in length of main and variations in boiler pressure. It is essential when the full output of the boiler is not used. Valve must be of suitable type, robust, compact, give accurate control and of adequate capacity. As a rough guide an efficient valve should pass steam as follows:

Valve Diameter	*Output lb/hr*
1 in.	900
1½ in.	1,600
2 in.	3,000

Where a reducing valve is not used, the area being steamed must be correctly related to the boiler output (see Table 1 on page 9).

2. *Condensate.* Remove condensate at further end of main by means of a suitable trap.

3. *Distributors.* Pay careful attention to pipe sizes in headers and distributors, particularly where a reducing valve is used. Do not throttle the steam flow. Reduce pressure loss due to friction to a minimum. Recommended sizes for a 1½ in. main are shown in Fig. 12: with a reducing valve (A, B) and without one (C). Y pieces are preferable to headers for splitting the supply. They are less weighty and cumbersome and give smaller resistance to flow.

Injection of Steam

1. *Rate of Injection* should not exceed 18 lb/sq.ft/hr, i.e., at least 54–60 sq. ft should be sterilized at one time for every 1,000 lb/hr of steam output from the boiler. Match the size of plot to the steam output of the boiler. The correct rate is most easily set by allowing 1½ min for every 1 in. depth of soil being sterilized, e.g., if soil being sterilized to a depth of 12 in. work should take about 20 min. If the time of cook is longer, the rate can be adjusted accordingly.

2. *Design of Equipment.* For the above rate of working (18 lb/sq.ft/hr) the pressure should be 2 p.s.i. in the injection pipe when ⅛ in. diameter holes used. Holes should be spaced so as to give 2½–3 holes per sq. ft of soil surface.

3. *Hoddesdon Pipes.* Pairs of ⅛ in. diameter holes at 5 in. centres.
Pipes up to 9 ft long should be 1 in. internal diameter, over 9 ft long should be 1¼ in. diameter.
Distance apart of pipes not greater than 1¼ times their depth below the soil surface.

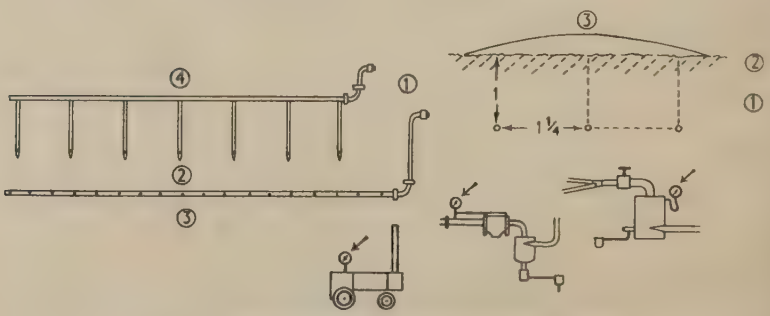


Fig. 13. Injection of steam, the soil and pressure gauges

4. *Spiked Pipe.* 9–15 ft long with 13 in. long spikes spaced 12 in. apart along pipe. Each spike with $3 \times \frac{1}{8}$ in. diameter holes. Pipes placed 12 in. apart.

The Soil

1. *Moisture Content.* Soil as dry as reasonably possible. Leave previous crop in without water for as long as possible to dry out the soil. Fuel consumption in ton/acre, for a sterilization depth of 23 in., can be as low as the figures for dry soil condition, given in the following table:

	Light Soil	*Heavy Soil*
	ton/acre	
Dry	24	27
Wet	38	58

2. *Tilth.* Soil well broken up. No large lumps in top 2 in.

3. *Cover* with tarpaulin, plastic sheeting or 1 in. granulated peat. Sheeting should cover each plot with a small overlap and should remain on at least 20 min after the cook is completed. Plastic sheet preferable to tarpaulin: cheaper, better insulator, spreads any escaping steam over surface and avoids wastage: edges must be weighted to keep in place. Peat should only be used when required as a soil improver; unsuitable for use very frequently.

Pressure Gauges

A pressure gauge is essential on the boiler and on the down-stream side of a reducing valve where this is used. Pressure gauges can also be used on the header or distributor as a check on injection rate, but they are not essential if the size of plot being steamed is matched to the output of the boiler. Pressure gauges should be of good quality and regularly tested to ensure accuracy.

Appendix II

GUIDE TO COSTS OF SOIL STERILIZATION

As a general guide to the possible cost of soil sterilization in glasshouses, the following figures have been prepared from actual results obtained on holdings in 1958. The cost of labour, material and equipment has been calculated at the rates ruling at the time (1958) and allowances for insurance, maintenance and depreciation have been included. The figures have been based on a minimum of an acre of glass; with smaller areas the cost would be relatively higher.

Steam Sterilizing

	£
Labour	240
Fuel	200–300
Insurance, feed water treatment, repairs, depreciation	60–110
	500–650

The fuel cost varies with the type used and the method of firing. The lower figure is for coke breeze with forced draught and the upper figures for furnace coke. There is also a wide variation in the quantity of fuel used, the range being 27–45 tons/acre. The high figures are largely a reflection of inefficient working due to wet soil and too high a rate of steam injection.

The figures for labour do not vary very much with most types of equipment if the cost of the necessary prior cultivation when using spiked pipes or spike harrows is also included. The cost of this cultivation is about £100/acre. With plough-type steaming grids hauled through the soil by winch the labour cost is substantially reduced to about £150/acre.

Chemical Sterilizing

With chemical sterilization, it is necessary to prepare the borders before application, and in order to make a valid comparison with steam the cost of prior cultivation amounting to £100/acre should be added to the totals given in Table 4.

TABLE 4

Material and quantity per acre	*Cost of material*	*Cost of application (labour and equipment)*	*Total cost*
			£
Formaldehyde (500 gal) . . .	135	65	200
Emulsified tar acid (350 gal) . .	125	65	190
DD mixture (400 lb) . . .	40	40	80
DD mixture (400 lb) and solubilized tar acid (100 gal) . . .	105	65	170
Chloropicrin (34 gal) . . .	220	130	350
Dithiocarbamates (110 gal) . .	180	50	230

Appendix III

PROPERTIES OF STEAM

The amount of heat available in a given quantity of steam may be found by referring to a steam table, but for convenience the essential information is given in Fig. 14 for steam at atmospheric pressure (0 p.s.i.) and 80 lb per sq. in. (80 p.s.i.). The solid black line (XABY) shows what happens when water is heated at atmospheric pressure. If 1 lb of water at freezing point is heated, its temperature rises steadily and it takes in what is called sensible heat at the rate of 1 B.t.u. for each 1°F rise in temperature (see the definition of a British thermal unit). When the temperature of the water has reached its boiling point (212°F), 180 B.t.u. of sensible heat have been added (shown by the line XA).

At boiling point (point A in Fig. 14) further heat does not raise the temperature but it changes the water into steam. A large amount of heat is needed to evaporate the water and this latent heat, as it is called, is 970 B.t.u. per lb water at atmospheric pressure (B-A in Fig. 14). Point B represents the stage where the pound of water has been completely evaporated. If further heat is now added the temperature of the steam increases above boiling point, and is called superheated steam. The amount of superheat is measured in °F above the boiling point (shown by the solid line BY).

Steam which has no superheat, i.e., between points A and B, is referred to as saturated steam and if it contains no unevaporated moisture, as at point B, it is called dry saturated steam (D.S.S.).

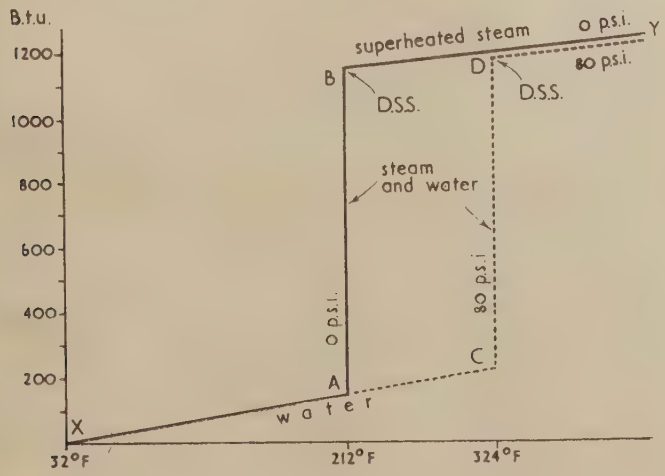


Fig. 14. Heat available in 1 lb steam

At 0 p.s.i.: B—A=1,150—180= 970 B.t.u.
At 80 p.s.i.: D—A=1,184—180=1,004 B.t.u.

The steam passed into the soil during sterilizing is normally saturated and contains a percentage of unevaporated moisture which should preferably be as small as possible. By the time the soil has reached boiling point, 212°F, all the steam condensed in it has become water at that temperature. So that if dry saturated steam at atmospheric pressure were used for sterilizing soil, it would give up its latent heat of 970 B.t.u. per lb to the soil but would retain its sensible heat of 180 B.t.u. per lb. In other words, the proportion of steam heat which can be usefully employed is $\frac{970}{970+180}=0{\cdot}84$ of the total heat given to it, assuming that the water fed into the boiler is at freezing point. Usually, of course, feedwater is warmer than this and so the proportion of useful heat is a little more than 0·84.

In practice the steam used for sterilizing soil is always under pressure, even if only slight. The effect of pressure on the heat content of steam is shown by the dotted line ACDY in Fig. 14. The line XAC represents the heat given to a pound of water initially at freezing point, after being injected into a boiler at 80 p.s.i. After injection into the boiler the water is heated rapidly to its boiling point (point C=324°F), which is 112°F higher than the boiling point at atmospheric pressure (point A). As steam is given off from the boiler, the pound of water is evaporated and eventually becomes dry saturated steam (at point D). It will be seen that at pressures above atmospheric pressure, the sensible heat (line XC in Fig. 14) is greater and the latent heat (line CD) is less than at atmospheric pressure (lines XA and AB respectively). With a pressure of 80 p.s.i., the net result is that the total heat of steam is very slightly greater (about 3 per cent more) than at 0 p.s.i.

When dry saturated steam at 80 p.s.i. is used for sterilizing soil, it becomes water at 212°F, so that the heat usefully employed is the difference between points D and A, i.e., 1,004 B.t.u./lb. The heat remaining in the condensed water is 180 B.t.u./lb (difference between X and A) and the proportion of the total heat usefully employed is $\frac{1{,}004}{1{,}004+180}=0{\cdot}85$ (compared with 0·84 for steam at atmospheric pressure).

It is thus seen that the proportion of heat available for sterilizing soil is hardly increased at all by steam pressure and that for all practical purposes each pound of steam contains about 1,000 B.t.u. of available heat, whatever the pressure of the boiler.

The use of a high-pressure steam boiler has one small advantage arising from the 3 per cent greater total of heat of the steam produced. When steam is reduced in pressure by passing through a reducing valve or other orifice, or by passing through a long main of small diameter, this 3 per cent of its total heat becomes available, either to superheat the steam if it started as dry steam at high pressure, or, what is more likely, to evaporate some of the water droplets contained in the steam. About 4 per cent of wetness may be removed from steam in this way. This apparent advantage is, however, quite a minor one, because low-pressure boilers can easily be designed to produce superheated steam, whereas most high-pressure boilers produce steam containing at least 5 per cent of unevaporated moisture.

Appendix IV

FLOW OF STEAM THROUGH MAINS AND PERFORATED PIPES

The pressure drop in a steam main may be calculated if the factors on which it depends are known, but, owing to the high steam velocities and relatively small pipe diameter used, some of the formulae in common use by engineers give misleading results.

The following formula gives the pressure drop between any two points 1 and 2 and usually points at the two extremities of the main, and is sufficiently accurate for general use:

$$P_1^2 - P_2^2 = \frac{70\,L}{d^5}\left[\frac{W}{1{,}000}\right]^2$$

L=distance between points 1 and 2 on the main in ft.
P_1 and P_2=steam pressure (absolute) in p.s.i. (=14·7 plus gauge pressure) at points 1 and 2 respectively.
d=internal diameter of main (actual, not nominal) in in. (see Table 5).
W=rate of flow of steam in lb/hr.

The rate of steam flow through holes in pipes is related to the steam pressure as follows:

$$W = 310\,A\sqrt{P}$$

W=rate of flow in lb/hr.
A=total area of holes in sq. in.
P=gauge pressure of steam in the pipe in p.s.i.

TABLE 5

DIMENSIONS OF MEDIUM TUBE

(identified by the blue band)

Nominal diameter	*Actual internal diameter (average)*	d^5
in.	*"d" in in.*	
1	1·079	1·46
1¼	1·388	5·15
1½	1·588	10·1
2	2·060	37·1
2½	2·644	129
3	3·146	308
4	4·142	1,219

Printed in England under the authority of Her Majesty's Stationery Office by James Townsend & Sons, Limited, Exeter.

Ps.308314 Wt.3588/4979 K.40 10/59 J.T.S.Ltd. 327

CLEAN SOIL and CLEAN HOUSES for a CLEAN CROP

SOIL STERILISERS

VAPAM

The multi-purpose soil steriliser

TRADE MARK OF ROHM & HAAS COMPANY PHILADELPHIA

Steriform/Formaldehyde

STERIFORM consists of 38% w/v Formaldehyde, especially treated to prevent the formation of sludge. It is a powerful fungicide, but has only limited activity against soil insect pests.

Sterisol

STERISOL is a white free-flowing emulsion containing special phenol fractions of very high insecticidal efficiency. The emulsion is completely stable and a non-oily diluted wash is produced. The phenol fractions used in STERISOL are of the high-boiling type so that fuming does not take place.

P.B.I.DD

Root-knot Eelworm causes severe damage to lettuce, cucumbers and tomatoes. Potato Root Eelworm attacks tomatoes grown in infested soil.

PAN BRITANNICA INDUSTRIES LIMITED

WALTHAM ABBEY, ESSEX

Modern aids to higher yields

SHELL D-D SOIL FUMIGANT

In glasshouses...

for the control of root-knot eelworm and potato-root eelworm.

Outdoors...

for the control of bulb-root rot on daffodils.

SHELL D-D is a liquid mixture of chlorinated hydrocarbons derived from petroleum. It offers a thoroughly efficient, convenient and inexpensive soil fumigation, applied indoors by injector gun and, outdoors over larger areas, by an injector unit which seals in the fumigant as it is injected.

SHELL D-D *has a number of practical advantages:*

being volatile, it produces fumes that reach every particle of soil without upsetting the moisture content or tilth. It is easy and convenient to apply. It gives considerable increase in crop yields. Application costs are low, as incorporation into the soil becomes part of the normal cultivational routine.

Full details and supplies from your local Shell Chemicals Distributor

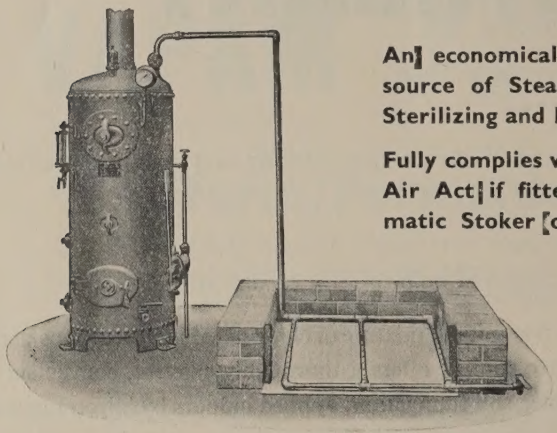
SHELL

YOU CAN BE SURE OF SHELL CHEMICALS

'SHELL' is a Registered Trade Mark

For Soil Sterilizing

Coltman Steam Boilers



An economical and efficient source of Steam energy for Sterilizing and Heating

Fully complies with the Clean Air Act if fitted with Automatic Stoker or Oil Burner

Illustration shows 5' × 2' Boiler with Grid for sterilizing ¼ cubic yard of Potting Soil

COLTMAN

Boilers are also made with evaporations up to 2600 lb/Hr.
Write for free literature

WALTER W. COLTMAN & CO. (BOILERS) LTD.

CENTRAL BOILER WORKS, GREAT CENTRAL ROAD, LOUGHBOROUGH

Telephone: Loughborough 2351

Telegrams: Boilers, Loughborough